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SIMULATED OCCUPANCY OF SHELTERS

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SIMULATED OCCUPANCY OF SHELTERS

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DETACHABLE ABSTRACT

This report reviews and evaluates work performed by several contractors participating in the OCD fallout shelter ventilation program, including field ventilation tests using simulated occupants and the development of analytical models for prediction of ventilation requirements.

A series of meaningful experiments by the several contractors provided data in support of the analytical model. Emphasis is placed on weather criteria, which play an important part in determining required shelter ventilation rates. The adequacy factor (AF) method is found to be the most satisfactory criterion to date, by virtue of its basis upon simultaneous dry-bulb and wet-bulb temperatures available from the U.S. weather bureau. Curves of adequacy factor as a function of ventilation rate have been developed for 91 cities in the U.S., and shelter ventilation requirement maps showing isoventilation contour lines across the U.S. have been prepared from the AF curves. The data are based on an adiabatic (non-conducting wall) model, i.e., the shelter load is assumed to be entirely removed by the ventilating air. The ventilation rate required is found to be greatly influenced by selection of the shelter effective temperature/adequacy factor criterion (SET/AF criterion).

The required ventilation rates based on the adiabatic wall shelter model is found to produce realistic estimates under summer conditions for above-ground shelters. For below-ground or partially below-grade shelters, the ventilation rate required can be reduced if the

surrounding soil is substantially below the ambient dry-bulb temperature. Further studies are required to develop a method of applying correction factors, such as for heat transfer, to the basic required ventilation rate of the adiabatic model shelter.

The simulated occupant (Simoc) used in the tests is found to be a reliable approximation to the human metabolic load.

The relationship of weather data gathered by the Weather Bureau to microclimate shelter area data requires further study. Also found to require further study are methods of presenting required shelter ventilation rates, and the degree of detail within geographical areas.

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ABBREVIATIONS

AF	Adequacy factor
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
Btu	British thermal unit
DB, DBT	Dry bulb, dry-bulb temperature
ET	Effective temperature
°FET	Effective temperature in degrees Fahrenheit
GARD	General American Research Division of General American Transportation Corporation
GATX	General American Transportation Corporation
h	Hours
NBS	National Bureau of Standards
occ	Occupant
RVR	Required ventilation rate
SET	Shelter effective temperature
SET/AF	Shelter effective temperature/Adequacy factor criterion
Simoc	Simulated occupant
WB, WBT	Wet bulb, wet-bulb temperature
USWB	United States Weather Bureau

I INTRODUCTION

During crowded confinement in fallout shelters, the heat generated within the shelter must be removed in order to maintain habitable conditions. The principal heat source would be the metabolic output of the shelter occupants. The majority of the shelters designated would be occupied only during the short emergency period, and probably would not be equipped with any ventilating or cooling system. It would therefore be uneconomical to equip such space with a normally unused cooling system; accordingly an emergency standby ventilation system using ambient outdoor air would clearly be the most practical and economical.

A program involving a series of fallout shelter ventilation tests was initiated by the Office of Civilian Defense in 1959. One of the earliest reported fallout shelter test was conducted in a prototype 100-man shelter constructed by the Naval Radiological Defense Laboratory near Oakland, California. Work tasks investigating environmental conditions in fallout shelters ventilated with ambient outdoor air were assigned to several contractors. During the period from 1961 through 1965 approximately 50 shelter ventilation tests were conducted in designated shelters at various locations in the U.S. Both above-ground and below-ground types were tested. Most tests were scheduled to be performed during the summer months, but a few winter tests were also included. Simocs (simulated occupants) were used to represent the human load in the shelters. The results of each of the tests were presented in reports by the contractors.

Under the present project, SRI has reviewed the contractor reports, including those received during 1966. At the suggestion of OCD evaluation was to be based principally upon studies of the reports submitted. Direct discussions with the authors of the reports were to be kept to a minimum.

The present report discusses and comments on particular highlights of the contractors reports, including such principal parameters as weather criteria, ambient and shelter psychrometric conditions, and heat transmission through shelter boundaries. Also discussed are shelter models, both adiabatic and nonadiabatic, the ventilation adequacy factor, and the transient analysis. Some detailed presentations are included in the appendices, but in general, involved repetition of the contents of the reports studied has been avoided. Conclusions regarding the general validity of techniques used by the various reporting contractors are set forth, followed by recommendations concerning future work to be done, which, in the Institute's judgment, is necessary to enable a final evaluation to be made of the work already carried out and discussed in this report.

As the evaluation work proceeded, it was realized that some of our conclusions and recommendations were, of necessity, educated judgments rather than purely the outcome of strictly logical arguments. Therefore, in trying to avoid unconscious bias during the evaluation qualified personnel other than the listed authors were consulted. They include Mr. John J. Eige, Mr. Elmer Robinson, Mr. Frank C. Allen and Mr. Leonard Power of SRI, and Dr. Jen-Yu Wang of San Jose State University, to all of whom we express our deep gratitude.

II OBJECTIVE

At the beginning of this project, the stated objectives were reviewed and considered in the light of overall program goals. Without quoting at length from the work statement, the general task under this project has been to review and evaluate the work done by various contractors using Simocs in connection with the fallout shelter ventilation test program. As part of this project, SRI has made recommendations concerning further work that may be needed to achieve the eventual goals of the OCD Shelter Ventilation program.

While studying and evaluating the contractor reports, SRI has particulary kept in mind the need to assess the degree to which information gathered from various sources could be applied in synthesizing a simplified and universally useful set of procedures for establishing shelter ventilation requirements.

The OCD Project 1200, "Environmental Characteristics of Shelters," is concerned with "control of the shelter environment." The work, as presented in this report, reviews the experimental and analytical work performed by the contractors on this subject.

III SUMMARY

A. Reference Parameters

In order to evaluate the results of shelter ventilation tests, numerical values for the various design criteria were suggested. As a reference, 400 Btu per hour per occupant was used as the metabolic load and an effective temperature (ET)* of 85°F for the habitability criterion. Space allotment was fixed at 10 ft^2 per occupant.

The parameter of 400 Btu/hr-occ is the total of the sensible and latent metabolic load, and appears reasonable. Controls on the Simocs varies the sensible-to-latent heat ratio as a function of dry-bulb temperature. Acceptance of 85°F ET as criterion for habitability is more difficult to defend, as discussed at greater length in Part 2 of Appendix A. Part 3 of Appendix A deals with the uncertainties surrounding the space allotment figure.

B. The Simoc

The "Simoc" (simulated occupant) used in all shelter experiments is an electromechanical device to simulate the human metabolic load by generating sensible heat and water vapor in an amount comparable to that generated by an average person. The two types of Simocs developed for use in shelter tests are the individual Simoc, developed by the National Bureau of Standards (NBS) and the mass Simoc developed by General American Transportation Corporation (GATX), which simulates up to 60 sedentary adults. In the larger shelters (occupancy greater than 50 persons), no appreciable discrepancy was observed when the two types of Simocs were interchanged. Simocs eliminate the effects of possible variations found in the assortment of live occupants and allow direct comparison between the results of different tests.

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* ASHRAE[1] defines effective temperature as an empirical sensory index, combining into a single value the thermal effect of temperature, humidity, and movement of air upon the human body. Combinations of temperatures, humidities and air velocities that produce the same feeling of warmth are assigned the same "ET" value.

A third type of Simoc considered is one suggested by the University of Florida. It makes use of the test vehicle, which, in addition to supplying ventilating air, also provides the sensible heat and water vapor equivalent to the rated shelter metabolic load, thereby serving as an external Simoc. This method has only been used once and therefore must be further proven to be acceptable as reliable load simulator.

Simocs are discussed further in Part 2 of Appendix B.

C. Shelter Tests

1. General

In the simulated occupancy tests of shelters, one objective was to obtain data with which theoretical methods for analyses of heat-mass transfer in and around a shelter environment could be verified. Another objective was to obtain data for the derivation of interim empirical relationships among significant parameters.

Since costs would not permit the construction of test prototypes to represent the many conditions, field tests were made in such shelters as were available or in structures having similar thermal characteristics.

The majority of the shelter ventilation tests were performed by supplying the shelter with ventilating air, conditioned to follow a design day cycle. The internal load of the shelter was adjusted to simulate an occupancy allotment of 10 ft^2 per occupant. For most of the tests the ventilation rate was adjusted so that the shelter effective temperature stabilized in the region of 85^oF ET.

The shelters tested are not a statistical sample of all shelters in the country, since their number is neither large enough nor representatively random. However, from the study of the test procedures and test results, the authors feel that tests have been conducted in a sufficient variety of shelter models and shelter geography; accordingly, the environmental responses resulting from the Simoc load and ventilation by ambient air are generally representative of the expected behavior of

most shelters. The authors also feel that not enough tests were conducted using ambient air and extending the full confinement period of 14 days; indeed, only the Providence test was conducted in this manner. Additional tests of this type are needed to verify the computer program and to investigate shelter heat transfer behavior over a 14-day confinement period.

2. Use of Conditioned Air

The development and the usage of the design day cycle have been somewhat controversial. The original purpose of using conditioned inlet air was to provide a controlled design summer weather cycle, usually warmer than the ambient cycle, for determining ventilation rates required in the shelter (see Part 4 of Appendix B). However, in many cases, this purpose was defeated, principally because it is impossible to determine the extent of the error introduced. The rate of heat transfer through the boundaries would be greater than if ventilation were with ambient air already at summer design-day level; therefore a lower required ventilation rate will be indicated by such a test. The lower required ventilation rate obtained using this method would of course, be inadequate unless some idea of the increased transmission loss is known and a correction factor applied. In later tests, compensating heaters were used; however, the exact magnitude of the heater load is dependent upon the knowledge of the transfer coefficient.

Conditioned air can be used with little error, however, in several cases. In ventilation tests of under-ground shelters in the summer months for instance, the walls are near the maximum temperature and are relatively insensitive to the ambient air temperature change. There would be little variation if conditioned air slightly warmer than the ambient is used in such a test.

3. Live Occupancy Shelter Tests

A brief mention is made of the live occupancy tests.

In addition to the shelter ventilation tests using Simocs, a few tests were performed with human occupants as participants. These tests,

however, were restricted to one or more of the following conditions:

(1) In several tests, only healthy young males were used

(2) Duration of confinement was relatively short (i.e., 24-hour tests, 48-hour tests) when participation was by the general public.

(3) Shelter effective temperature was maintained at a relatively low effective temperature.

Only a very few live occupant tests were performed for a 14-day period. These involved tests by the USNRDL[31] and the University of Georgia.[32]

At least two tests, the University of Georgia test at Athens, Georgia, in 1962-63[33] and the University of West Virginia test at Morgantown, West Virginia in 1966[34] involved occupants of both sexes and ages ranging from about 8 months to over 70 years and represented somewhat a cross section of the populace, although all were volunteers. At the National Naval Medical Center in Bethesda, Maryland,[21] comparative tests were run using live occupants and Simocs.

Much has been learned from these tests of occupant behavior, tolerance to confinement, equipment handling, and equipment performance. Because of the restricted nature of the tests, however, the information is limited. There would exist a high element of risk in conducting a full-scale shelter experiment involving a cross section of the populace for a 14-day test under extreme design shelter conditions.

Regarding the problem of shelter ventilation, the live occupancy tests conducted in real designated shelters can be the proving ground for the application of ventilation rates predicted by analytical methods. These field studies can include the study of procedures that can be used to obtain shelter physical data and applicability of the adiabatic wall model ventilation rate if such data are too difficult to obtain. With known shelter parameters, studies can also be made on the average metabolic heat output of the occupants.

The authors feel that the live occupancy tests should be continued and progressively include the studies of all pertinent problems involving survival, including ventilation, equipment use, food, sanitation, management, and general response of the occupants to the shelter environment.

D. Work Performed by Various Contractors

Several contractors participated in the shelter ventilation test program. The role of the National Bureau of Standards was to investigate the use of mathematical models in digital computer programs as means of predicting shelter thermal responses of primarily underground shelters. Their work consisted of analysis of under-ground heat conduction, ground temperature studies, derivation for a digital computer program applied to NBS test shelters, and related computer calculations carried out and compared with experimental data. The paper entitled "Outdoor Air Psychrometric Criteria for Summer Ventilation of Protection Shelters," written by personnel of NBS,[21] offers much basic information on the approach for the consideration of various weather criteria. A brief analysis given is based on the adiabatic wall model and the paper serves as an excellent guide for preparing a design method for shelter ventilation systems.

The University of Florida has conducted shelter ventilation tests in 25 below-ground shelters in various parts of the U.S. Much of the data obtained were supplied to NBS for their analytical studies. The program consisted of a series of simulated occupancy tests of shelters ranging in size from a 12-occupant shelter to a 1000-occupant shelter. The scope of work consisted largely of instrumenting and performing measurements of shelter climate and wall conditions over the test period. The majority of the tests were conducted using Simocs and supplying various rates of ventilating air while observing the shelter conditions. One test compared the thermal effects within a shelter under two methods of test, the use of human occupants as shelter load and the use of Simocs. It concluded that a Simoc generating 400 Btu/hour was a close representation of the human metabolic load and that the thermal effects of the shelter resulting

from both test methods were closely duplicated. The experimental techniques developed and the data compiled by the University of Florida shelter tests serve as a valuable source of information for the study of shelter ventilation.

The General American Transportation Corporation (GATX) conducted a series of shelter tests involving above-ground and basement shelters. In conjunction, a computer program was developed by which it was possible to predict the transient shelter conditions using the test input parameters. Comparisons with the shelter test data showed close agreement with the predicted results. Experimental results were also compared with the analytical solutions based on an adiabatic shelter and with results using the time average temperatures (part 4 of Appendix F). Based upon the adiabatic shelter, a method was developed for determining the ventilation rate using the adequacy factor. Data from the weather studies of 91 cities was used for developing adequacy factor-CFM curves (Part 2 of Appendix F). The experimental and analytical work performed by GATX produced useful and valuable information directly applicable to the Shelter Ventilation Program.

The Guy B. Panero, Inc. and ITT Research Institute also performed ventilation tests. The University of Syracuse conducted analytical studies applying both the analog and digital computers (See Appendix C).

One of the earliest shelter tests using Simocs was performed by the USNRDL.

E. Criteria for Determining Shelter Ventilation Requirements

1. General

In order to develop a method for predicting shelter ventilation requirements, it is necessary to establish the weather criteria for different geographical locations, the design criteria for shelter environment, based on physiological tolerance information, and the parameters for the various shelter properties.

For establishing weather criteria, both the dry-bulb temperature (DBT) and wet-bulb temperature (WBT) in a coincident form must be considered. The ASHRAE Guide[1] has independent listings for the principal cities of the design DBT and WBT for a 1, 2.5, and 5 percent design day. National Bureau of Standards has shown in their paper[20] that using these noncoincident, independent values of DBT and WBT in combination to define a single-point psychrometric criterion resulted in a "percent design day" that was extremely conservative. Moreover, the "percent design day" was highly inconsistent, varying widely with geographical location. It was not possible, therefore, to establish a consistent criterion based upon a single psychrometric point. Further studies should be made to develop a method for adjusting the single point criterion, since this method would be useful for specific ventilation calculations. Its advantage lies in the fact that the basic "percent design day" information is readily available and the simple ventilation rate curves can be used (Figs -2 and D-3). Because of the inconsistent nature of the unadjusted single point criterion, the adequacy factor was developed.

The adequacy factor (AF) is the proportion of a total time unit (usually one year) that a shelter condition may be expected to be maintained at or below a given effective temperature when a given ventilation rate is used. Adequacy factors are derived from the hourly coincident DBT and WBT (Part 2 of Appendix D). From detailed coincident weather data, curves of adequacy factor as a function of ventilation rate for a family of effective temperatures were developed by GATX for 91 principal cities in the U.S.

The AF is generally interpreted as the portion of one year during which an adequate shelter condition can be expected. However, since climate is grouped more or less according to season, the occurrences of inadequate days are not distributed evenly throughout the year. It is highly probable that almost all of the inadequate days would occur during the four to five month summer period; for the remainder of the year, the AF would be close to 100 percent. It would be more meaningful to use AF for only the grouped portion of the year where it is applicable.

In order to apply the curves of AF as a function of ventilation rate, the "Shelter effective temperature/adequacy factor" criterion must be established. The determination of this criterion would result from the study of physiological tolerances and the establishment of a probability factor of not exceeding the shelter design temperature. The establishment of this criterion would probably involve an administrative decision. The importance of a prudent choice of the "shelter effective temperature/adequacy factor" criterion is stressed, since it influences greatly the ventilation rate requirement.

2. Ventilation Requirements Based on an Adiabatic Shelter

Ventilation requirements for an adiabatic wall model shelter can be obtained from the adequacy factor curves such as contained in this report (Fig. D-5 and D-6). It is recommended, however, that initially a direct adjustment in the required ventilation rate (RVR) value be made (Part 2-d of Appendix B). In regions where the RVR is small, the shelter ET reaches a very high level in the extreme summer climate (i.e., at 99 percent adequacy factor), however, it has been determined that by a very slight increase in the RVR this condition can be avoided. In the regions where the RVR is high, the ventilation rate can sometimes actually be decreased somewhat with little change in the shelter condition, even at extreme summer climate. The ventilation rate obtained is for an adiabatic shelter and can serve as a basic value to which correction factors may be applied.

The several contractors have concurred on the use of the adiabatic model as a basis for determining shelter ventilation rate for the following reasons:

(1) It is a simple and convenient method.

(2) Only the weather and "Number of occupant" information are used, thereby minimizing introduction of errors.

(3) It decreases the risk of inadequate ventilation, since ventilation rate predicted is the maximum rate that can be required (assuming solar effects are negligible).

(4) It is a close approximation for determining ventilation rate for many shelters varying over a range of configuration.

(5) It is entirely feasible to develop a procedure for adjusting the basic adiabatic ventilation rate.

The principal adjustment that would be made to the adiabatic shelter ventilation rate is the adjustment for boundary wall losses. It would be impractical to attempt a detailed study of heat transfer properties of each shelter. However, it may be feasible to develop a procedure for establishing a conservative value of boundary loss expressed as a percentage of total shelter load, depending upon the geographical location and type of structure. (It is our understanding that information regarding the type of structure was included in the Phase I study of the National Fallout Shelter Survey.) Determination of the value of the heat transfer coefficient can probably be avoided. Much information was obtained regarding the proportion of heat loss through the boundary walls from the many shelter experiments and should prove useful in establishing a procedure for estimating the loss. The corrected RVR would be the adiabatic rate reduced by an amount approximately equal to the boundary loss proportion of the total heat generated in the shelter. Under the same survey, shelters which would not need adjusting, that is adiabatic shelters, can definitely be identified.

3. Ventilation Requirements Based on the Hourly and Daily Average Weather Data

The study of extensive data showed that the RVR's obtained from the hourly or average daily weather data do not differ greatly in areas in which the RVR is small, but significant differences are noted in areas where the RVR is large. It was also mentioned above that in these regions where the RVR is high, the ventilation rate can be decreased somewhat with little change in the shelter condition. This would support the fact that RVR's obtained from the hourly or the average daily data

would not differ greatly, especially after the aforementioned adjustments have been made. As previously mentioned, the difference in ventilation requirement is influenced more predominantly by SET/AF criterion that is chosen.

Results of many shelter tests have shown that the daily amplitude of the shelter effective temperature is small (within ±2°F). There was also close agreement between the predicted and the test results using average values. It is therefore recommended that for the interim the analyses of shelter environment be based on the daily average temperature.

For establishing basic data such as the AF-RVR with SET parameters, it is the recommendation of the authors that hourly data be used, since such data are readily available. There is no reason to dispense with valuable information by averaging, especially since hourly data is used to obtain the averages.

4. Computer Program

A parallel effort to the above was the development of computer programs for transient analysis of shelter environment. Different programs were developed independently by GATX, NBS, and the University of Syracuse. This sophisticated method of determining shelter ventilation rates using a computer program would take into account the transient weather cycle and the transient heat transfer through the boundary walls. Detailed input parameters would be required. Moreover, the validity of the various input information must be established; otherwise reliance might be placed on overly precise calculations based on uncertain parameters. The several computer programs developed, yielded results that agreed closely with the experimental results when actual weather inputs were used together with detailed information regarding the shelter properties. It is questionable how readily such a detailed method of computation can be applied to the vast number of designated shelters. The computer program has served, however, to provide analysis for transient shelter conditions. As a result of its application to the several experiments performed, a degree of confidence has been established in its validity although (for the present) its universal application is impracticable. At this time it would be well to integrate the several computer

programs into one, incorporating the merits of each. Although the immediate and extensive application of such a program may not be feasible, it does serve as a basic tool for research and analyses.

For predicting ventilation requirements through the use of the computer program, a design day cycle is needed for the weather input. Because of its dynamic nature, difficulties are encountered in the development of the design cycle in which the coincidence of the design DBT and WBT can be considered. It is noted in Part 1 of Appendix D that by using the noncoincident data of the percent design day dry-bulb and wet-bulb record as listed in the ASHRAE Guide an overly conservative criteria results. A more realistic approach to the development of a design cycle is one in which the hourly points in the cycle are established by using the percent design day WBT's for each hour in combination with a DBT cycle in which each of its hourly points would be made up of the DBT's that occur most frequently with the corresponding WBT. This technique really represents an effort to partially retain the coincidence of DBT and WBT.

The computer program has been proven only to the extent that the analytical results agree closely with the test results when the input data of the actual ventilating air is used. In order to utilize the computer program for predicting the ventilation rate, the dynamic weather information in the form of the design day cycle must be used. No data have been presented comparing the ventilation requirements obtained from the dynamic method with those obtained from static method (adequacy factors curves). The validity and extent of application that can be made of the computer program can probably be seen by such comparisons.

F. Weather Criteria

The reliable prediction of shelter ventilation requirements depends in turn upon the reliability of available weather data and its correlation to the local shelter climate condition. Since there may be differences in the microenvironment of the weather station and the shelter, there may be deviations in the weather of the two locales. It would, of course, be a tremendous task to perform climatic measurements of each shelter area for correlation to the weather bureau records. However,

grouping or classifying the shelters would decrease the number of tasks. A critical condition would nevertheless exist, if the weather conditions in the shelter vicinity were more severe than that obtained from the area weather bureau data. Since the parameter of climatic data is so dominant in the determination of shelter ventilation requirements, correlation weather studies by key population areas would be recommended. Studies can initially be conducted on a few large metropolitan areas. Dr. Wang, a meteorologist consultant has recommended the weather studies be conducted adopting the volunteer observation system as used by the USWB.

The ventilation requirement data for all parts of the U.S. must be presented in such a form so as to be readily usable by the shelter analysts, architects, and engineers. One form of presentation that has been prepared is the ventilation rate contour map. The contour lines on the map appear to be too coarse, especially in the northern area. The lines are not sufficiently definite of the ventilation rates of local areas. It would be unwise to interpolate between some of the very wide gaps of contour lines. A more specific breakdown is recommended such as those that show detailed contour lines by states rather than that of the whole U.S. on a small map. The use of closer contour intervals must incorporate data from more weather stations. Listing of ventilation rates by towns or by counties is another example of detailed breakdown. It is our understanding that such tables and maps are presently being prepared.

IV CONCLUSIONS AND RECOMMENDATIONS

The extensive shelter ventilation test program carried out by the several contractors has provided much information and data on the transient response of the shelter interior environment. To some extent, the approximate magnitude of heat removed from media other than the ventilating air has been determined. The shelters tested do represent quite a wide distribution with respect to climate, size and type. There was not as much opportunity for selectivity as one would desire in locating and obtaining access rights for prototype test shelters, most of which were privately-owned buildings. Of necessity, the tests were made in spaces that were not in normal use. Available shelters that were too large for manageable tests were sometimes scaled down by constructing insulated partitions and controlling dry-bulb temperature in the adjacent area. Most shelters were restricted to the single-room type; a few had multiple rooms. Several groups of tests were essentially parallel studies conducted by different contractors. Basically all test procedures were similar.

This report was prepared following the review of numerous reports published by several contractors who had performed shelter ventilation tests. Certain recommendations are presented as a result of the review and are directed particularily toward the establishment of reliable working techniques for determining shelter ventilation rates required using ambient air. While the report recommends the acceptance of certain methods developed by the contractors for determining ventilation rate, additional work is also recommended, mainly to verify the method of ascertaining certain parameters and criteria.

Conclusions and recommendations are as follows:

(1) The Simoc

The Simocs have proven to be a reliable simulator for the human metabolic load and have been used successfully in the determination of shelter ventilation requirements. The Simocs

may not be usable, however, as a human stimulator in an air-distribution study of the shelter interior, since the individual-type Simocs occupy excessive space, and the mass Simocs have a built-in fan which stirs the air excessively (see Part 2 of Appendix B).

(2) Adiabatic-Wall Model Shelter

The term "adiabatic," as applied to shelter wall properties, is a loose one that has been used in the sense that no heat is transmitted through boundary surfaces. The term used in heat-conduction analyses to describe a surface that is impervious to heat is "insulated" or "non-conducting." Tables and graphs for determining ventilation rates were developed using the adiabatic-wall model shelter because of its simplicity, and the fact that it approximates the requirements for most above-ground and numerous below-ground shelters.

(3) Consideration of Boundary Heat Losses

It is recommended that studies be continued toward a feasible means for determination of shelter boundary losses in terms of percent of total rated load. The purpose is to establish a correction factor for adjusting the basic adiabatic ventilation rate where the boundary loss rate is substantial. It is not known just how many shelters fall into this category, since it was reported that a large portion of the shelters in the country can be considered as essentially adiabatic. The recommendation would represent an effort to reduce ventilation rates where conductive losses are large. A preliminary census indicating the approximate number of nonadiabatic shelters in the country would determine the feasibility of pursuing this program further (see Part 2 of Appendix F).

(4) Computer Program and the Design Day Cycle

A considerable amount of effort has been expended in developing a computer program that can predict analytically the transient condition of the shelter. This program has been proven valid as a result of comparisons with several shelter tests. These comparisons were made, however, using the then-available experimental input data of diurnal cycle and not the predicted summer design day cycle. In order to make full use of the computer program to predict the required ventilation rates completely (independent of experimental data, since these are available only for test shelters), the dynamic weather information for a particular locale must be available and used. Since the computer program has been developed to its present level, it is recommended that a design day cycle be developed at least for the principal cities so that the computer program can be used to maximum advantage when basic studies are necessary. The development of design day cycles would be desirable as an adjunct to or replacement for annual data. Such data are needed for the design of environmental

control systems when transient states are considered and for evaluation of physiological responses in a hot environment when conditions temporarily exceed those necessary for habitability.

Much data from Simoc tests have been accumulated. It is recommended that these data be studied exhaustively to evaluate transient responses of shelters and to determine parametric relationships that describe these responses. The computer program appears to have been proven on a basis of comparison with several shelter tests, but since only the Providence test was of full 14 days duration using ambient air, it is recommended that additional such tests be performed for supporting the evaluation of transient responses applying to an extended period. The purpose would be to establish a sound analytical procedure which would then become more useful for the predictive evaluation of a shelter (than an experimental procedure). It would then be available for application in basic research programs of shelter ventilation. As a result of our study, we envisage three different levels of approach to the shelter ventilation problem: the adiabatic wall model, corrections to be made to the basic adiabatic model, and detailed analysis by use of the computer program.

(5) Adequacy Factor and "Shelter Effective Temperature/Adequacy Factor Criteria"

It is recommended that the adequacy factor method of determining basic ventilation requirements be accepted for the present. In order to determine the ventilation rate from the adequacy factor-ventilation rate data, the "shelter effective temperature/adequacy factor" criterion must first be established. A thorough study for determining this criterion is recommended, since the ventilation rate required is largely dependent upon the choice of this criteria. This involves further investigation on:

(a) the validity of the effective temperature index relating to physiological tolerance at high humidities, high effective temperatures, and prolonged exposure.

(b) conditions that may be expected during the "inadequacy" period,

(c) weather design criteria, and

(d) economic factors.

The tolerance of "nonstandard" subjects to heat stress, cold stress, and dehydration have not been well defined. The study should also include the feasibility of using only the summer months as basis for the adequacy factor, since it principally applies only to the summer period. There are some differences in the ventilation requirements obtained by

using the hourly data and the daily average data as basis, but the choice of the above criterion exercises a much stronger influence on the required ventilation rate (see Part 2 of Appendix D and Figs. D-5 and D-6).

(6) Further Study of U.S. Weather Bureau Data

Curves of adequacy factor as a function of ventilation rate based on the adiabatic-wall model shelter have now been developed for 91 principal cities of the U.S. For each city, a set of curves (with effective temperature parameters) were based on the data of the U.S. Weather Bureau for that city. Actually each of these data represents the weather condition for a very large area, and it is suspected that variations from this data may exist in isolated locations within each such large area. It is strongly recommended that studies be made to compare Weather Bureau data with the climate condition in the immediate vicinity of the shelter location, at least for a meaningful number of sample areas. A study would be made for the purpose of assurance against the design of underrated ventilation systems for shelters which may be located in areas whose ambient climate is in fact more severe than that indicated by the U.S. Weather Bureau data (see Appendix E).

(7) The Single Psychrometric Point Criteria

It is recommended that studies be made to determine the feasibility of using the single-point weather criterion (defined by the design DBT and WBT) as a basis for determining ventilation rates. The principal reason for this recommendation is that data for the various "percent design day" are readily available (in handbooks and manuals) for all the principal cities in the U.S. Such data are presented independently for the dry-bulb temperature and the wet-bulb temperature. For establishing a single psychrometric point criteria, it must retain the feature of coincidence between dry-bulb and wet-bulb temperatures. If the proposed studies should prove that the percent design day data may be validly applied through the introduction of correction factors, it would be merely a matter of using already available data, so that it would not be necessary to develop adequacy factor curves for additional cities. The single-point criterion would be most convenient for engineers or architects who need to study or design ventilation systems based on local conditions (see Part 1 of Appendix D).

(8) Use of Summer Conditioned Air

We are of the opinion that an unnecessary number of tests were performed using inlet air conditioned to the summer weather cycle and an insufficient number of tests using ambient inlet air. The purpose of conditioning inlet air was to avoid the abortive effects of cool atmospheric conditions that would frequently occur during a series of tests.

However, the ventilation rate thus obtained will be in error to some degree, depending upon the extent of the artificially produced temperature differential between the conditioned and ambient air. Tests using ambient air would not necessarily provide the maximum ventilation rate but would be more realistic and meaningful for use as input data for proving the analytical solution (see Part 4 of Appendix B).

(9) Natural Ventilation

Reports submitted on natural ventilation to date present data and conclusions defining only the particular shelter tested. As of this writing, a general analysis has not been made. The next logical step suggested in the study of natural ventilation is analytical rather than experimental. A better definition of the parameters and relationships involved in natural ventilation would provide guidance in planning experimental work.

(10) Presentation of Ventilation Information

Once the ventilation requirement information is determined, a format must be devised for making such information available to the shelter analysts or other ultimate users of the information. One such method has been developed in the form of geographical maps showing isoventilation line contours whose ventilation rates are obtained from the adequacy factor curves.

However, depending upon the capability of the user of the information, it may be desirable to present this information in other forms, e.g., for a nontechnical group such as local CD and certain field personnel, a more specific assignment of ventilation requirements for a specific area is required. Such information could be presented in tables classified according to state, counties, and cities. For technical personnel, a concise presentation of the derivation of adequacy factor as well as the basic adequacy factor - cfm curves and possible correction factors should be made available so that they will be equipped with knowledge enabling them to solve a particular problem of local nature.

(11) Human Occupancy Tests as Source for Additional Data

Shelter tests using live occupants would no doubt be continued. It is recommended that a maximum feasible number of test observations be made in these tests, since they represent a more realistic shelter condition. The tests conducted in designated shelters should be the proving ground for application of predicted ventilation rates using the design weather ambient air conditions. Studies should include the feasibility (the difficulty or ease) of obtaining shelter parameters that affect the determination of the ventilation rate.

The foregoing has discussed the need for or the effect of carrying out the recommendations of the SRI report. Of greater importance is the fact that as the studies set forth are carried out, the result will be to bring about the integration of the individual but interdependent criterion which are essential for determining shelter ventilation requirements. It is important to point out the fact that the determination of the ventilation rate required does not entirely solve shelter environmental control problems. Closely related are the problems of:

(1) Supplying the required quantity of air into the shelter and

(2) Distributing the air within the shelter so that the environment of every part of the shelter can be made habitable (see Appendix H).

The ventilation rate or occupancy capacity may be affected greatly by the failure to obtain distribution in shelters with complex floor plans. These are distinct problems in themselves and further work is being done under separate contracts.

It would appear necessary to initiate early discussions between appropriate SRI, OCD, and contractor personnel in order to plan means for carrying out these recommendations.

In the opinion of the authors, the several contractors have performed very creditably during the whole Shelter Ventilation Program, especially in view of the very scattered form and limited availability of background information pertinent to the task. Selection of test-shelter locations extended over areas of various climate so that test results are generally representative. Early stages represented a period of learning and involved the evolution of basic method approach to shelter tests, both as to technique and the development of suitable equipment, including the test vehicle and the Simocs.

Tests have become progressively more meaningful and have finally resulted in a wealth of significant information on shelter response as a function of load, ventilating air and shelter properties, and also, the development of computer programs through which it has been possible to find comparative, even though limited agreement with experimental findings.

Appendix A

REFERENCE PARAMETERS USED IN INITIAL DESIGN CRITERIA

In order to evaluate the results of shelter ventilation tests, it was convenient to establish meaningful references. The following numerical values were suggested by OCD as tentative design criteria:

Total metabolic heat energy output	400 Btu/h-occ
Habitability criterion	85^{o}F ET
Occupant space allotment	10 ft^2/occ

While these figures are not to be cons‘ ;ed as established design criteria, they do enable comparison and evaluation of various test results.

1. Metabolic Heat

While energy output varies greatly with the type of individual (sex, age, size) and with the degree of activity, etc., 400 Btu/h per shelter occupant at rest appears to be a realistic average value of the total heat energy released.

2. Habitability Criteria

A number of indices might be used as habitability criteria, but no single index seems to be completely valid at present. The effective temperature (ET) index is widely known, and therefore has been used extensively in the shelter ventilation evaluation program. ASHRAE (Ref. 1, Chap. 7) defines ET as "an empirical sensory index, combining into a single value the thermal effect of temperature, humidity and movement of air upon the human body. Combinations of temperatures, humidities, and velocities which produced the same feelings of warmth were assigned the same ET value." The numerical value of ET is that of the dry-bulb temperature at saturation; by definition, all psychrometric conditions producing the equivalent thermal sensation are assigned the same value. An ET of 85^{o}F has been used to date as a reference criterion

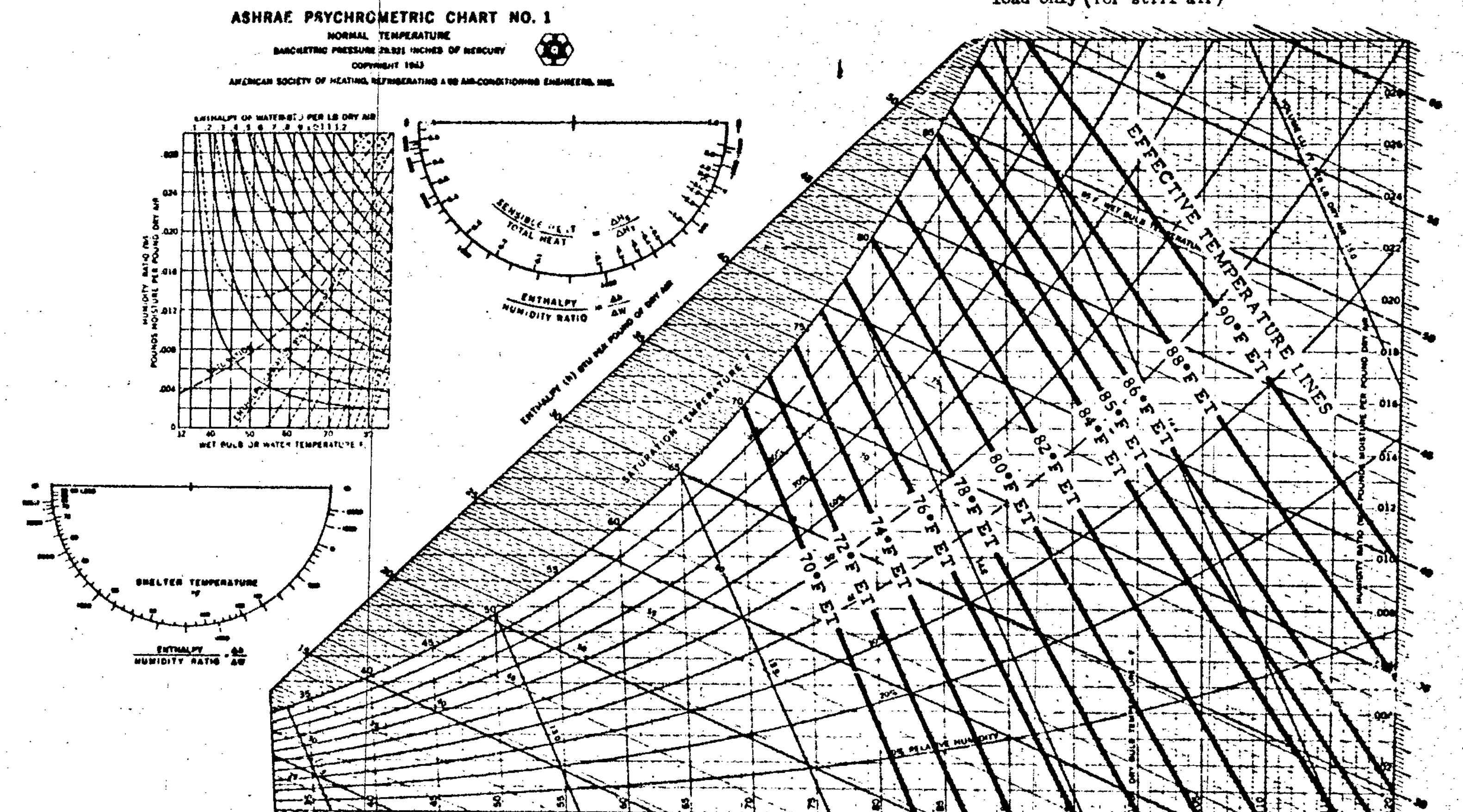
for shelter climate. In Fig. A-1, ET lines are drawn on a psychrometric chart. It is seen that the effective temperature can be defined by two parameters such as the dry-bulb and wet-bulb temperatures.

Questions have been raised with respect to the validity of ET as a shelter design criterion, particularly as to whether the ET index remains valid at the high humidity levels that would probably prevail in a fallout shelter environment. This uncertainty stems from the fact that the ET index was originally developed for air conditioning engineering, where comfort is the sole concern. The application of ET index in cases of prolonged exposure requires further study. In the present discussion of the 85°F ET criteria, it would be inappropriate to establish a certain limiting ET as a survival limit for the majority of the population on the basis of the sparse physiological data available. Table A-I, reproduced from Ref. 2, is an example of one physiological data. (This is not construed to be a summary of current data.) A more specific and detailed table, similar to Table A-II, will be required before any decision can be made. In the meantime, other indices, such as the strain index of Lee and Henschel,[3] should also be reviewed and compared.

In the absence of a definitive value, a limiting range, e.g., from 82°F to 85°F, can be established as an initial design criterion until confidence is established in a specific value after weighing the factors of physiological tolerances. This avoids premature "over-acceptance" of a provisional reference value, which once issued would be difficult to alter. As a typical example, early in shelter ventilation program, 3 cfm per occupant was mentioned as the minimum ventilation required. An instructor at one of the OCD Area University Architectural and Engineering Development Centers notes that, following the mention of this value in one course, many of the designated shelters were tagged with a ventilation requirement of 3 cfm per occupant. Yet all tests and computations have shown that it is impossible under summer conditions in any part of the country to maintain an effective temperature as low as 85°F with this ventilation rate.

PSYCHROMETRIC CHART FOR ESTIMATING FALLOUT SHELTER VENTILATION EFFECTS

Shelter temperature protractor based on 400 Btu per hr - occupant metabolic load only (for still air)



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SOURCE: Ref. 2

FIG. A-1 PSYCHROMETRIC CHART WITH EFFECTIVE TEMPERATURE LINES

Table A-I

PHYSIOLOGICAL RESPONSE TO ELEVATED EFFECTIVE TEMPERATURES*

Type of Individual	Effective Temperature, °F				
	75	78	80	85	86
Acclimated	C	C	W	W	SD
Healthy 25 year old males	C	W	SD	AD	F
45 - 65 years old	C	SD	AD	F	
65 and older	C	SD	F		
Infants	C	AD	F		
Obese	C	SD	F		
Limited water (loss > 3 liters)	C	SD	F		
Metabolic disorders	C	W	AD	F	
Skin disorders	C	W	F		
Heart and Lung disorders	C	SD	F		
Stomach disorders	C	W	F		
Mental abnormalities	C	AD	F		

C = Comfortable
W = Warm
SD = Some Distressed
AD = All Distressed
F = Failure (a term analogous to the military concept of a casualty)

* Time of exposure was more than 24 hours.

Source: Ref. 2 (Note: Is an early data and is not construed to be a summary of current physiological data.)

Table A-II

ILLUSTRATIVE DESIRED PHYSIOLOGICAL DATA

Type of Individual	Average Number of Hours before Failure at Effective Temperature, °F				
	75	78	80	85	86
Acclimated	--	--	--	Indefinite	72
--	--	--	--	--	24
--	--	--	--	--	--
--	--	--	--	--	--
--	--	--	--	--	--

Therefore, it must again be emphasized that a value of 85°F ET has been used only as a reference criterion to enable comparison of various test results.

3. Occupant Space Allotment

A figure of 10 ft^2 per occupant has been used as a provisional design criterion for occupation density in shelters for computing the shelter load. This area allotment is probably the minimum space required per occupant when all are lying prone. Shelter experiments to date using simulated occupants have all been based on the 10 ft^2 allotment and the ventilation rate using ambient air in these tests was adjusted to maintain a shelter ET of 85°F or lower. Nevertheless, it should be kept in mind that the space-per-occupant parameter will be one of the most difficult to predict or assume since the number of people that would occupy a particular shelter is always uncertain. The validity of the "10 ft^2/occupant" criterion is often questioned in considering occupation density of shelters.

It seems unlikely that, in a time of crisis, strict control can be maintained over the flow or migration of potential occupants toward specific designated shelter areas, especially in crowded downtown districts where the population density depends on the time of sampling. Individuals would attempt to reach the nearest available shelter, and this random selection would inevitably result in over- or under-occupancy in specific shelters.

This situation may be still further aggravated unless there is fairly uniform distribution of shelter facilities, since the chances are equal that a nucleus of shelters could be invaded and overcrowded* than others which are more isolated. It will be difficult to avoid this, since suitable shelter structures may be randomly scattered.

Because of the many uncertainties concerning occupant density tolerance, separate studies have been made on the subject of overcrowding.[4]

* By present difinition, a space allotment of less than 10 ft^2 per occupant is referred to as "overcrowding."

Appendix B

GENERAL DISCUSSION OF SHELTER VENTILATION TESTS

1. Objectives of the Shelter Tests

Generally stated, objectives of the shelter ventilation test program are:

(1) To establish a method for determining the minimum ventilation rate required for maintaining habitable conditions within building types that may serve as possible fallout shelters, as once the ventilation requirements are known, the ventilation system can be specified.

(2) To obtain experimental data for use in verifying the analytical method of predicting shelter psychrometric conditions resulting from ventilation with ambient air.

Initially the objective of the shelter ventilation tests that were conducted by the several contractors was to obtain some idea of the magnitude of the ventilating air flow required in order to maintain the shelter effective temperature (SET) below 85°F. Early tests evaluated the validity of Simocs as simulators, the method of measuring heat transfer, and the suitability of instrumentation.

2. Simocs

a. Function

A "Simoc," or "simulated occupant," is an electromechanical device designed to simulate the human shelter occupant in such a way that it will generate heat and water vapor in amounts comparable to the average person.

b. Types

Two specific types of Simocs were developed for shelter tests. The individual type developed by National Bureau of Standards was designed to simulate the metabolic heat and water output of a single sedentary adult.[5] The "aggregate" type or "mass" Simoc developed by General American

Research Division (GARD) of General American Transportation Corporation (GATX) has the capability of simulating up to 60 sedentary adult shelter occupants.[6]

Recently, Professor Flanigan and co-workers at the University of Florida suggested the possibility of a dual-purpose shelter ventilating test vehicle itself to serve both as a ventilating air supply equipment and a single "external" Simoc. The test vehicle[7] in addition to supplying ventilation air would also provide an amount of heat and water vapor equivalent to the metabolic load (Ref. 8, p. 195). It was anticipated that through this technique, the Simocs used in previous tests may prove to be unnecessary; however, an insufficient number of tests using this technique has been conducted to support this contention.

Generally, individual Simocs were used in the small, family-type shelter tests, and aggregate Simocs were used in the large, community shelter tests. In a few of the tests conducted by the University of Florida, both individual and aggregate Simocs were used at the same site in order to compare tests results.[9,10,11] It developed that aggregate Simocs were not appropriate for family-type shelters (around 10 occupants), since the Simoc blower upset the ventilating air flow and the heat transfer process. In a community shelter, with occupancy greater than 50, no appreciable discrepancy could be detected when the two types of Simocs were interchanged.[11]

c. Calibration

The aggregate type Simocs could be calibrated to within 3 percent of the standard metabolic heat and water output of the average sedentary adults within the normal operating temperature range of 65°F to 100°F.[6] This 3 percent accuracy is sufficiently realistic, since the metabolic energy output (i.e., 400 Btu/hr per occupant) is a statistical average over a large number and a wide variety of people. The occupants in a particular shelter would be a random sample of the entire population, and their average metabolic output would probably deviate from the "Standard" value by more than ±3 percent. Furthermore, the percentage

errors of other shelter ventilation test instruments range from 2 percent to 5 percent (e.g., the anemometers used to measure the ventilation rate have ±5 percent accuracy).

d. Comments

Except for their inability to reproduce the physiological and psychological responses of live human occupants as a result of extended term of confinement in an extreme environment, the usefulness of Simocs in shelter tests is much greater than that of live occupants. They eliminate the effects of possible variations in the "mix" of shelter occupants and consequently allow a direct comparison between the results of different tests as far as the number of occupants is concerned. That is, so long as the number of simulated occupants remains the same, a direct comparison between test results for otherwise different shelters is possible without concern for the effect of sex, individual characteristics, or age groups.

Although the Simocs have proven to be reliable simulators for the metabolic load, it is our opinion that they will not be usable where air distribution studies of the shelter interior must be made. The individual Simoc is constructed so that it contains the surface area of the average human body, but occupies a volume far in excess of the human body due to the Simocs' cylindrical shape. Since they occupy excessive space, the air circulation in the shelter may be quite different than with the presence of live occupants. The mass Simoc on the other hand, is a small unit which can simulate loads up to 60 occupants. The fan built into the Simocs can stir the air quite thoroughly, thereby disrupting any air distribution study of the ventilating air.

3. Test Procedures

a. Typical Test Procedure

Sites usually chosen for shelter ventilation tests were heavily constructed buildings that met the general requirements for use as fallout shelters. In a typical test program, thermocouples and other sensing devices were installed in the shelter area and its boundaries (including

the back fill material and soil outside the walls in the case of an underground shelter) to record temperature, humidity, and other pertinent information. The shelter floor area was measured, and the number of occupants was determined on the basis of 10 ft^2/occupant. The shelter load was in turn based on the number of occupants.

From local weather data, diurnal temperature cycles representing the extreme summer weather were developed and designated the design day temperature cycle (Sec. VIII-C). The shelter was ventilated with conditioned air whose psychrometric conditions conformed to the design day cycle. Conversion of the ambient air to conform to the design day cycle was performed by a specially designed test vehicle.[7] Temperatures, humidities, and other information measured from the various sensors, were regularly recorded.

b. Variations in Test Procedures

Slight procedural differences distinquished almost every shelter ventilation test. There were two main reasons for these variations in test procedures: One was to take advantage of experience gathered from earlier tests, the other was to permit studies of the effect of new parameters. The significant variations in test procedures are presented; it is not intended to account for all the minor differences.

i. Variations in Ventilation Rate

Constant ventilation rate tests--The ventilation rate was held constant throughout the entire test period to permit studies of shelter temperature responses as a function of time.

Adjustments in ventilation rate--Adjustments in ventilation rate were made whenever the SET either exceeded or fell short of 85°F. The purpose of the adjustments was to determine the ventilation rate for that particular shelter that would maintain the SET in the proximity of 85°F.

"No Ventilation" Tests--These tests were performed to permit studies of the heat-transfer characteristics of a particular shelter. The adjusted heat generated by the Simocs caused the SET to rise until

the generated heat was balanced by the heat transmitted through the shelter boundaries. A separate experiment simulated the rate of rise of the SET during the button-up period.

ii. Variations of Inlet Air Conditions

Design day cycle for a specific test location--The majority of shelter ventilating tests were done with the inlet air conditioned to conform with the design day conditions of each particular test location.

Design day cycle of other geographical areas--During a portion of GATX Wilmington test,[12] the summer design day conditions for Phoenix and Milwaukee were used in addition to the Wilmington design day cycle.

Use of ambient air--The ventilating tests using ambient air, though comparatively few in number yielded what we regard as the most useful information. For further discussion, see Sec. X-D.

c. Discussion

The test reports indicate that in most cases the ventilation rates were altered several times during the course of each test. In almost all instances the changes were too frequent. As indicated by both the results of NBS computer calculations[3] and the tests of University of Florida,[8] three or four days were usually required for the environmental conditions in the below ground shelters to stabilize after each change in ventilation rate. There is thus a question as to the validity of test data taken where the periods between changes of ventilation rates were less than three days.

If the ventilation test results are to be used principally to verify the theoretical studies and the related computer program, a procedure using ambient air at a constant ventilation rate throughout the test would be most informative.[14] It is not imperative that the ventilation rate produce a critical SET, since the same temperature data compiled during the test can be used in the analytical model for comparison of the analytical results with the test results.

4. Use of Conditioned Air for Design Day Simulation

The large number of uncertain parameters involved in shelter ventilation problems makes it extremely difficult to arrive at precise and valid solutions. It would appear then, that experimental ventilation tests should be designed to deal with as few uncertain parameters at one time as is possible--preferably one. The use of Simocs to simulate live occupants in most of the shelter tests being evaluated, for example, is a good example of an attempt to eliminate the inevitable inhomogeneity of live occupants. The no-ventilation tests were also a thoughtful attempt to isolate that portion of the problem dealing with heat transmission through shelter boundaries.

On the other hand, justification of conditioned ventilating air in most of the tests is unclear. The majority of the early shelter ventilation experiments were carried out using conditioned air, i.e., ambient air conditioned to an appreciably higher effective temperature. Accordingly, a new psychrometric element was added to the heat transfer problem, and the quantity of heat transmitted through the shelter boundaries became a function of the artificially produced environment. The rate of heat transmission through shelter boundaries represents a major "uncertainty" in the overall shelter ventilation problem.

The original purpose of using conditioned inlet air clearly was to simulate an ambient environment representing the summer design criteria, thereby enabling determination of the ventilation rate required to maintain the shelter condition at a tolerable level. However, in many cases, this purpose was defeated, principally because it is impossible to determine the extent of the error introduced. If conditioned ventilating air can be used to simulate a summer design-ambient-environment, the actual ambient air surrounding the shelter during the test is cooler than the air being introduced to the shelter interior; hence, the rate of heat transfer through the boundaries is greater than in the case of ventilation by ambient air at summer design-day level. Because of this greater transfer rate, a lower flow rate of conditioned air would actually be indicated during the test to maintain a design environment

within the shelter. The required ventilation rate predicted using this method would, therefore, be inadequate unless some idea of the transmission loss is known and the ventilation rate value is corrected.

GATX attempted to compensate for the additional heat loss through the shelter boundaries by supplying extra heat to the shelter to offset the additional loss. During the tests, the heat output was modulated according to the ambient diurnal swing. In order to determine the quantity of heat to be added, it was necessary to determine the wall transmission coefficient. The energy balance method of obtaining the transmission loss was used, followed by the solution for the transfer coefficient. The coefficient obtained was also checked with that obtained from the heat flux meters. Unfortunately, the degree of accuracy of the heat transmission coefficient determined in such circumstances is in question.

The basic heat transfer equations illustrate the compounding effect of the total error when the transfer coefficient is in error. If Q_c is the calculated heat loss through the boundary walls and Q_n is the calculated net heat loss if ambient air were at the same level as the conditioned air, then the compensating heat required would be:

$$Q_h = Q_c - Q_n = U_c A \left[(T_{sh} - T_{amb}) - (T_{sh} - T_{con})\right]$$

$$= U_c A \,(T_{con} - T_{amb})$$

where

U_c = calculated coefficient of heat transfer

A = area of boundary surface

T_{sh}, T_{amb}, and T_{con} = shelter, ambient, and conditioned air dry-bulb temperature, respectively.

If, for example, U_c is less than the true value of U by δU, then the boundary walls would actually transmit more heat than the quantity Q_c

by the amount $\delta UA\ (T_{sh} - T_{amb})$, and Q_h of the auxiliary heater would be underrated by the amount $\delta UA\ (T_{con} - T_{amb})$.

The ventilation rate required would tend to be decreased by both of the above factors. Thus, miscalculation of U coefficient has a compounding effect on the total error, in this case an underprediction of the required ventilation rate. The opposite will hold true if U_c is larger than the true value of U.

In exceptional cases, conditioned air may be used with little error. One such case is shelter ventilation tests conducted in the summer months of completely underground shelters. Because the soil temperature is close to its normal summer temperature and because of the relatively insensitivity of the ground temperature to the ambient air temperature change, the effect of introducing conditioned air slightly warmer than the ambient introduces very little variation from the results using ambient air. In cases where the percentage of total heat dissipated through the boundary walls is small, a substantial error in the determination of U results in a small variation in the ventilation requirements. Under such circumstances, the use of the conditioned air with make-up heaters would be justified.

Mention should be made here of the extensive theoretical calculations of heat loss made by Dr. Kusuda of NBS and his associates. While this formal mathematical formulation was extremely well executed, the team experienced great difficulty in establishing precise heat transfer coefficients for the various shelter boundary materials. If the amount of heat loss could indeed be accurately predicted, the shelter ventilation problem would almost completely be solved.

It is the opinion of the authors that one chief purpose of the experimental shelter ventilation test should be and is determining the validity of the theoretical model. Therefore, the use of ambient air in ventilation tests would produce the most informative data, for

comparison with the theoretical results, even though the temperature of the ambient air may be below that of some typical "design day" for a test location. It is apparent that GATX personnel came to favor this method during their shelter tests; during the later stages of the test program, ambient air was used for their Bozeman and Providence tests.[14,15]

Appendix C

SUMMARY OF REVIEWED CONTRACTOR REPORTS

Three contractors have done the greater portion of the work in shelter ventilation testing: National Bureau of Standards (NBS), University of Florida, and General American Transportation Corporation (GATX).

The chief role of NBS was to investigate the use of mathematical models in digital computer programs as means of predicting shelter thermal responses of primarily under-ground shelters. University of Florida carried out under-ground shelter ventilation tests at various geographical locations in the U.S. Much of the physical data were supplied to NBS to verify results obtained from the computer programs. GATX investigated both theoretically and experimentally the ventilation problems of above-ground shelters.

Other participating contractors included the University of Syracuse, Guy C. Panero Co., and IIT Research Institute.

1. Reports from National Bureau of Standards

In all the NBS work that SRI has studied, the test, the analyses, and reporting have been competent and thorough. Brief descriptions and comments on each of the seven reports are given in the following.

"Studies of Environmental Factors in a Family-Size Underground Shelter" (March 1961)[5]--Describes the construction and test of a very small underground shelter, suitable for six occupants, designed and built in accordance with OCD specifications. Extensive data were gathered from this test without reference to any prior mathematical theory or model. However, some of the results could be misleading because of the small size of the shelter and the fact that heated and conditioned air was used in cold weather. As an example, there was considerable condensation on the walls in most tests, enough to have a noticeable effect on the heat and

humidity balances. This may have been an artifact of the cold ground and heated air used, because in most subsequent summer (more realistic) tests by other contractors, condensation on the walls did not seem to be appreciable.

The small size of the shelter seems to present an unnecessary complication for later analysis. One ventilation unit of any reasonable size would be more than sufficient for such a small shelter, regardless of its geographical location provided that ambient can be used for ventilation. Furthermore, very small shelters are particularly difficult to simulate because of three-dimensional heat transfer, large surface-to-volume ratio, and the resulting high heat losses through the walls.

"Mathematical Analysis of Temperature Rise in the Heat Conduction Region of an Underground Shelter" (1962)[16]--Deals with transient heat conduction between deeply buried, idealized shelter shapes and their surrounding soil. The shapes of the shelter cavities are assumed to be cylindrical, spherical, etc., such that the solutions to the heat equation of these highly symmetrical shapes are readily available. Good explanations of the derivations and assumptions for the analytic formulas are given. It was found that a two-dimensional cylindrical model gave good results with the most probable parameter values for the one small family-size shelter that had been tested and reported in Ref. 5.

"Earth Temperature and Thermal Diffusivity at Selected Stations in the U.S." (February, 1965)[17]--Covers the fitting of assumed equations to earth temperature data previously gathered by various investigators. Least-square techniques were applied. The results of this study allow description of the ground temperature as a sinusoidal function of time of the year and depth from the surface, provided the following four parameters are given:

(1) Annual average temperature (air and ground approximately equal),
(2) Annual amplitude of surface temperature,
(3) Thermal diffusivity of the earth, and
(4) Surface temperature's phase angle, from 1 January.

An extensive computer program and resulting graphs and calculations are given. The calculations are based upon limited data taken for a variety of purposes by different investigators, mostly for undisturbed earth, on open flat ground, either bare or grass-covered. No report is given of the possible effects of locations in metropolitan areas where the land may have been excavated, back-filled, surrounded by other buildings, covered with concrete or asphalt, etc. Also neglected are various realistic factors that would tend to complicate the calculations, e.g., nonuniformity of the ground with depth; composite character of the walls and floor of the shelter, including the gravel or other fill beneath the floor; and the varying amounts of moisture that may be in the soil at different locations.

One potentially useful result of this paper is a table of average earth temperature to ten-foot depth at various locations in the country. This could be convenient in estimating heat loss through shelter walls if the shelter conditions correspond sufficiently to the idealistic assumptions made herein.

"Least Square Technique for the Analysis of Periodic Temperatures of the Earth's Surface Region" (September 1965)[18]--Gives a thorough mathematical treatment of the problem of finding the best fit of a sinusoidal temperature-variation curve to a large amount of miscellaneous data. A detailed evaluation of the analysis on our part did not seem warranted in view of the limited need for the results on this project and the length of time that would have been required to check on their particular uses of harmonic analysis, matrix algebra, variance analysis, and Monte Carlo simulation techniques.

"Numerical Analyses of the Thermal Environment of Occupied Underground Spaces with Finite Cover Using a Digital Computer" (1964)[13]--Outlines the derivation and some verification calculations for a digital computer program applied to three of the NBS tests of their six-man shelter and to one test by the University of Florida of their eighteen-man shelter.

The coefficients of heat transfer and water vapor transfer necessary for the computer solution were determined from previous extensive tests

of the two small shelters, but the coefficients were then later adjusted by trial and error to produce reasonable agreement between measured and computed temperatures. In order to achieve results from this sort of computer simulation that would be useful in design of the ventilation system for a given shelter, it would be necessary that all the data and coefficients that enter into the mathematical equations be available and invariant with time; in actuality, the many necessary numbers are neither available nor constant.

"Digital Computer Simulation of Thermal Environment in Occupied Underground Protective Structures" (January 1965)[19]--Describes four slightly different programs for simulating the temperature and humidity histories of shelters. These programs or mathematical models differ in the number and type of simplifying assumptions made regarding the homogeneity and three-dimensionality of the shelter boundaries. The objective of the study was to evaluate the accuracy of digital computer programs that had been substantially worked out in preceding projects. Computer calculations were carried out and compared with experimental data for seven different underground shelters under various conditions. The comparisons in general were good. From comparing the computed and measured results, NBS concluded that a given set of heat transfer coefficients could be applied for most of the summer shelter conditions encountered. These numbers may turn out to be very useful, but due to the limited amount of experimental data available NBS was not able to say how typical the numbers are on a nation-wide basis.

"Outdoor Air Psychrometric Criteria for Summer Ventilation of Protection Shelters" (January 1965)[20]--A very well thought-out and well-done piece of work, seeming to give practical results of ambient cooling. There is a good introduction and explanation of the problem, and the method of approach seems quite logical and thorough, without being overly elaborate. Analysis is based on the "adiabatic-wall model." Since this is the basis for our recommendations, Appendix D is devoted to the discussions of this model and it is not described in detail here. Suffice it to say that this rather short paper is filled with useful information, references to computer programs that are available to compute effective

temperature and to handle hourly coincident temperature data, and could stand alone as a guide for preparing a design method for shelter ventilation systems. The paper does not pretend to present a method for simulating the environment in <u>any</u> shelter under <u>any</u> arbitrary conditions; however, no such simulation is required for the design job at hand. The authors see the problem for a realistic engineering viewpoint and recognize that there are many parameters and characteristics of individual shelters which would nc remain constant with time even if they could be measured, so that any extensive analysis based on idealized numbers becomes of little practical use. Previous study results may still have application in future studies of heat transfer to large masses of earth in other problems, but they are not of importance in allocating shelter ventilating equipments.

From the brief descriptions of each of the seven NBS reports above, it is seen that the shelter ventilation research undertaken by NBS was done systematically. Even the initial experimental effort was designed to provide data for later analytical studies. The mathematical formulation of the problem indicated the importance of the properties of earth enveloping any underground shelter, and therefore initiated the study of earth temperature and thermal diffusivity. Realizing the complications involved in this problem, a digital computer program was devised to solve the mathematical problem, followed immediately by an evaluation of the validity of the program. The next logical step is to utilize the available computer program to study the influence of each of the large number of parameters involved in this problem. The result of this parametric study will hopefully eliminate some of the less influential parameters. Nevertheless, it can be expected that most parameters--among them the thermal coefficients--will remain. To date, these coefficients are not readily available for any random shelter, hence posing a big stumbling block to any further development of the digital computer program capable of simulating shelter environmental conditions. The same reasoning leads to favoring the adiabatic model, which does not require any knowledge of these coefficients.

2. Reports from University of Florida

a. General

Beginning early in 1962, the University of Florida participated in a research program instituted by the OCD to investigate environmental conditions in fallout shelters. Twenty-five shelter sites in various parts of the U.S. were chosen for shelter ventilation tests. Shelters were almost all of the below-ground or partially below-ground type and ranged in size from a 12-occupant family shelter to a 1000-occupant community-type shelter. Tests covered the period July 1962 to December 1964. Results of shelter tests were submitted in individual reports. A final report summarizing the test program was also submitted.

In a concurrent program, the National Bureau of Standards (NBS) investigated the use of mathematical models in a computer program as a means for predicting shelter responses resulting from variations of ground thermal properties, shelter configurations, and ventilation rates. Physical data obtained during the Florida shelter test program were supplied to NBS as input for checking the validity of results using the mathematical model.

The work program consisted of a series of simulated occupancy tests, principally in underground shelters under summer weather conditions encountered in various geographical locations in the U.S. Simocs were used to represent human metabolic energy release within the shelters. In most cases, the inlet ventilation air was conditioned to simulate a design summer day weather. The shelter ventilation test vehicle was used to supply the controlled inlet air. Shelters were instrumented as described in Part 3 of Appendix B. Reports were prepared for each shelter test, giving test results and including data sheets. In nearly all of the tests, the ventilation rate was varied and the rate required to maintain the shelter effective temperature (SET) near 85°F was determined.

b. Reports on Individual Shelter Tests

The following points up special features associated with certain shelter tests performed by the University of Florida.

(1) The Summerlin shelter[9] was a small family-type shelter with a capacity of 18 occupants at 10 ft^2/occupant. The shelter was unusual in that the shell was made of 1/8-inch steel plate place below grade, thereby preventing any absorption or release of moisture from the interior walls and eliminating this variable. Individual Simocs and mass Simocs were used interchangeably, but due to the small size of the shelter, results from the mass Simocs were not considered valid on account of the effect from the large fan. Heat balances were calculated using the method of total energy storage by the surrounding soil. Heat absorbed by the surrounding soil accounted for approximately 25 percent of the total, even though the ambient air ET peak was above 85°F, illustrating the magnitude of boundary losses for small shelters even in warm climate.

(2) The Napier shelter in Gainesville, Florida[11] was an earth-covered shelter designed for 100 occupants at a space allotment of 16 ft^2/occupant. During the series of tests, the individual Simocs were compared with the use of a combination of individual Simocs and mass Simocs. Data observed showed no discernible difference. A test was also performed to examine the reduction achievable in the ventilation rate due to auxiliary cooling devices. In one test run, cooling coil in a 18 X 35 X 9-inch enclosure was installed within the shelter area so that interior air was recirculated through the coil. Water was circulated at 12 gpm (6000 lb/hr). The inlet water temperature was relatively warm (72.2°F), but a water temperature rise of 3.45°F was recorded. The test took place in August 1962; however, a ventilation rate of 3 cfm per occupant maintained the SET just below 85°F. The water coils removed 51 percent of the total heat generated. Condensation collected and measured indicated a removal of 38 percent of the moisture generated by the occupants.

For shelters in locales where the supply of water is abundant the use of a water cooling system minimizes the air ventilation requirement. Further studies are necessary in order to specify the optimum cooling equipment that may be used for a particular shelter.

(3) At the Bureau of Yards and Docks Protective Shelter at the National Naval Medical Center in Bethesda, Maryland,[21] a test was performed during 17 February 1962 through 2 March 1962 by the Navy. One hundred human subjects were used as occupants. The shelter ventilation tests using Simocs conducted at the same site by the University of Florida during 28 February-11 March 1964 were designed to duplicate as nearly as possible conditions that prevailed during the manned occupancy test. The purpose was

to compare the thermal response of the shelter under the two methods of test and to confirm if possible, the validity of the test of shelters employing Simocs. The outputs from the Simocs were varied during the test. As a result of test data it was concluded that when operated at a rate of 400 Btu/hour total output, and with the latent heat portion of this output adjusted to conform with the shelter DBT, the individual-type Simocs closely duplicate the thermal effects of sedentary young adult males exposed to the same volume and conditions of ventilating air. Although additional series of tests using both human occupants and Simocs had not been performed, it is reasonable to conclude that Simocs generating 400 Btu/h/occ closely represent the human metabolic load when used in shelter tests.

(4) As part of a series of shelter tests, a fire test was conducted in an underground parking garage at Mercury, Nevada.[22] Fire was created on the ground above the shelter and was allowed to burn out completely. Test results showed that the amount of earth cover that was sufficient to protect against radiation was also adequate insulation to prevent the shelter from being thermally disturbed. Control of carbon monoxide, however, would be necessary.

(5) In a shelter test conducted at Lakeside, California,[23] an experiment was made as to the possibility of simulating metabolic load without the use of Simocs. Through means available in the air handling equipment trailer, the additional necessary sensible and latent metabolic loads were added to the ventilating air prior to being introduced into the shelter. Test results were compared with tests using Simocs and found to be coincident within the limit of experimental error. The convenience of using this method would depend upon whether there would be a need for the equipment trailer in any future shelter ventilation experiments.

c. Final Report

The final report[8] generally summarizes the shelter ventilation tests. Subject matter discussed in addition to the ventilation tests includes development of a parametric relationship, as follows:

A parametric relationship was developed of those parameters affecting the shelter environment and based on the correlation of test results. The basic equation takes the form $ET = A + B\left(1 - X^{-aT}\right)$, where X and a are constants to be determined. This relationship defines the

ET path, from the initial state of the shelter, as a function of the number of days of confinement. It is dependent upon:

(1) "A," the initial undisturbed ET of the shelter (in turn based on weather data and ground temperature).

(2) "B," the difference between ET at the start of the test and after stabilization.

(3) "T," the time in number of days expected for the shelter ET to rise to a certain percentage of the stabilization temperature. (This value is taken from the Drucker study[24] of the rate of temperature rise in a shelter.)

(4) A series of graphs developed from experimental data.

The applicability of the rate of temperature rise as defined by the Drucker information over a wide range of below-ground shelters is not made clear. Mention is made that a good agreement was indicated in a comparison of a plot of shelter conditions obtained using low flow rate, with the curve generated by Dr. Drucker. It would seem that this would limit the general applicability of the expression, and that for different shelter conditions, it may be required to use different values of T with respect to the same percentage of maximum temperature rise.

Accuracy of the equation depends on a relatively reliable design value of A. The set of curves obtained from experimental results are drawn on an average basis through scattered points. The value of B is obtained from the curve. It would appear that, if the quantity B is made known, the ventilation requirement for the shelter would be determined since B is dependent on the ventilation rate. The points along the experimental shelter temperature rise curve would denote the daily average shelter conditions. The hourly condition is defined by the assumed sinusoidal expression added to the basic relationship. A severe condition would be defined by the repetition of the periodic diurnal cycle of the design day superimposed on the basic curve. Although the report shows that the temperature rise curve developed using this method agreed closely with the curves of average daily temperatures from the Ft. Belvoir shelter experiment (and also the experiment by NBS), a more thorough analysis is necessary for its justification to the application to all under-ground shelters.

3. General American Transportation Corporation

a. Shelter Ventilation Tests

A series of shelter ventilation tests were performed by General American Transportation Corporation (GATX) during the period of October 1962 to September 1964. Shelters were mostly those above ground. All tests except the Chicago test were conducted during periods of warm weather, since the primary aim of the program was to consider summer ventilation requirements. It is generally concluded that tests have been conducted in sufficient combinations of shelter geographical locations, types, configurations, and sizes, to ensure a thorough study of parameters affecting shelter environment.

After complete evaluation of the shelter tests GATX recommends strongly that, for large above-ground shelters, the ventilation systems be designed to remove the entire thermal load generated within the shelter. For a below-ground shelter, a similar recommendation is made provided the summer soil temperature approximates the time average of the ambient dry-bulb temperature. Experimental data and results as well as the analytical studies support this recommendation. Experiments have also supported their recommendation that the 24-hour average temperature data be used to determine shelter conditions.

In the series of experiments conducted, considerable attention was given to the study of the heat-transfer phenomena through the shelter boundaries. In addition to temperature readings, heat transfer data were obtained by means of heat flux transducers placed in contact with the shelter surfaces. The magnitude of heat transfer was compared with the enthalpy balance and the conduction equation using the coefficient of heat transfer obtained from the ASHRAE Guide. Initially, wide discrepancies were found in the heat transfer values determined by the different methods, but with improvement of techniques and proper application of published transmission coefficient values, confidence was developed in the values obtained using the heat-flux transducers.

In their computer program (see next section) used for analytical prediction of shelter conditions, empirical data were supplied. The

analytical predictions agreed closely with the experimental results. In all tests it was shown that some energy was lost through the shelter boundary; however, most of the tests were conducted during a period when the ambient temperature was slightly lower than the design summer condition. It was concluded following the tests that only a small percentage (less than 20 percent) of the total metabolic heat generated within most large shelters will be lost by heat transfer during hot summer weather.

In the tests of Houston, Texas, Milwaukee, Wisconsin, and Wilmington, North Carolina, several auxiliary tests were performed in connection with the ventilation program. A nonventilated test was performed to gain knowledge of the transfer rates in the shelter walls. Only sensible heat was used for the internal load, and the heat output adjusted to maintain an equilibrium condition in the shelter. By observing the average temperature differential, the magnitude of the heat transfer coefficient was obtained.

A limited number of natural ventilation tests were performed. Average air flow rates were calculated using the water balance method of the moisture added to the shelter by Simocs. No general correlation could be obtained between the wind velocities, ventilation rate, and the shelter openings because of the limited extent of the tests but specific results were obtained for the respective shelters.

In the Wilmington above-ground test, inlet air was conditioned to simulate the summer design day of Wilmington, Milwaukee, and Phoenix in separate experiments. The excess transmission loss due to the difference between the average of the design supply temperature and actual ambient temperature was returned to the shelter by electric heaters. There was a substantial difference in the ventilation rate required when compensating heaters were used. In the Wilmington design day test where the comparison was made, the rate required was 20 cfm per occupant with h aters versus 9 cfm per occupant without heaters. The data showed, however, that the inlet conditions were not exactly the same. In the Milwaukee and Phoenix simulated tests, the only test performed was that of determining the ventilation rate required to maintain the SET to an average of 85°F.

The above tests were spread over a one-year period. Throughout this period, experiments in each phase of specific tests were of very short duration, the longest being three days. Results obtained were specific to the shelter under test.

Since the experiments were best studied by means of controlled ventilation rate, only a limited amount of effort was devoted to problems of air distribution and natural ventilation and much that was learned related to the individual shelters tested. However considerable overall knowledge was gained through these initial tests, which served as information sources during the development of the analytical program. As a result of experience gained during this period, techniques and procedures for subsequent tests were much improved.

b. <u>Tests for Evaluation of Analytical Work</u>

Under a separate contract, an analytical procedure for predicting the shelter conditions was developed by GATX. In the subsequent tests involving shelters at Bozeman, Montana and Providence, Rhode Island, the analytical method was used to predict the shelter conditions and the results evaluated by comparing the predictions with the experimental data.

The test at Bozeman[15] involved an above-ground shelter in which a corner portion only was used because of the large size of the total area. Thus two walls were exposed to the exterior while the remainder was adjacent to the interior area. This introduced an interesting problem in that when the analytical model predictions were compared with the test results, agreement was very close with the exception of one period when the weather had cooled suddenly. The deviation was due to the difference between the actual temperature response of the interior area adjacent to the shelter and the calculated response, since only the weather data and inlet conditions were used as input data. When the actual test data of the adjacent area was used, the predicted and test data were in agreement. The mathematical model has generally been proven; however, it was found that the model could not be applied to shelters adjacent to an unoccupied perimeter area. It is limited by the

inability to predict the adjacent interior temperatures. Based on experimental observations, however, it was concluded that the adiabatic model still applies for determining ventilation requirements of shelters adjoining a perimeter area.

In order to compare the psychrometric response of the area tested with that of the entire area, the entire floor area was evaluated analytically. A comparison of the analytical time history of the total area, the test data and the analytical results of the shelter test area showed close agreement. It was concluded, therefore, that the test area experimentally evaluated is representative of the total area.

The test at Providence, Rhode Island[14] was also performed in conjunction with the mathematical analysis. This 14-day continuous test, using ambient air at a constant supply rate, was the only such test of long duration and using ambient air. Valuable information was obtained regarding the relationship between adiabatic and nonadiabatic transient analysis, steady-state conditions based on the time average of the transient conditions, and the experimental results. The Providence test, because of its informative nature, i discussed more fully in Part 4 of Appendix F.

As a result of the emphasis on the adiabatic method of determining shelter ventilation requirements, GATX has developed a set of curves of Adequacy Factor as a function of ventilation rate based on the adiabatic model (see Part 2 of Appendix D). Further use of this information was made in developing isoventilation contour lines presented on a geographical map of the U.S. (Fig. D-8).

Other noteworthy GATX reports include Ref. 25, which summarizes the parametric studies of shelters; Ref. 26, which summarizes the experimental studies of the shelters tested; and Ref. 2, which presents the procedure for solution based on a simplified model.

The program undertaken by GATX on shelter ventilation requirements covered the evaluation of the major parameters. Thorough work was done in the performance of the tests and the correlation of the analytical and the test results in relation to ventilation requirements. The

problems of air distribution within the shelter and that of making air available to the shelter (natural ventilation, ventilation systems) are an extension of the ventilation program now being undertaken.

4. Reports from Syracuse University

The following two reports prepared by a group led by Prof. Drucker of Syracuse University have been reviewed by SRI.

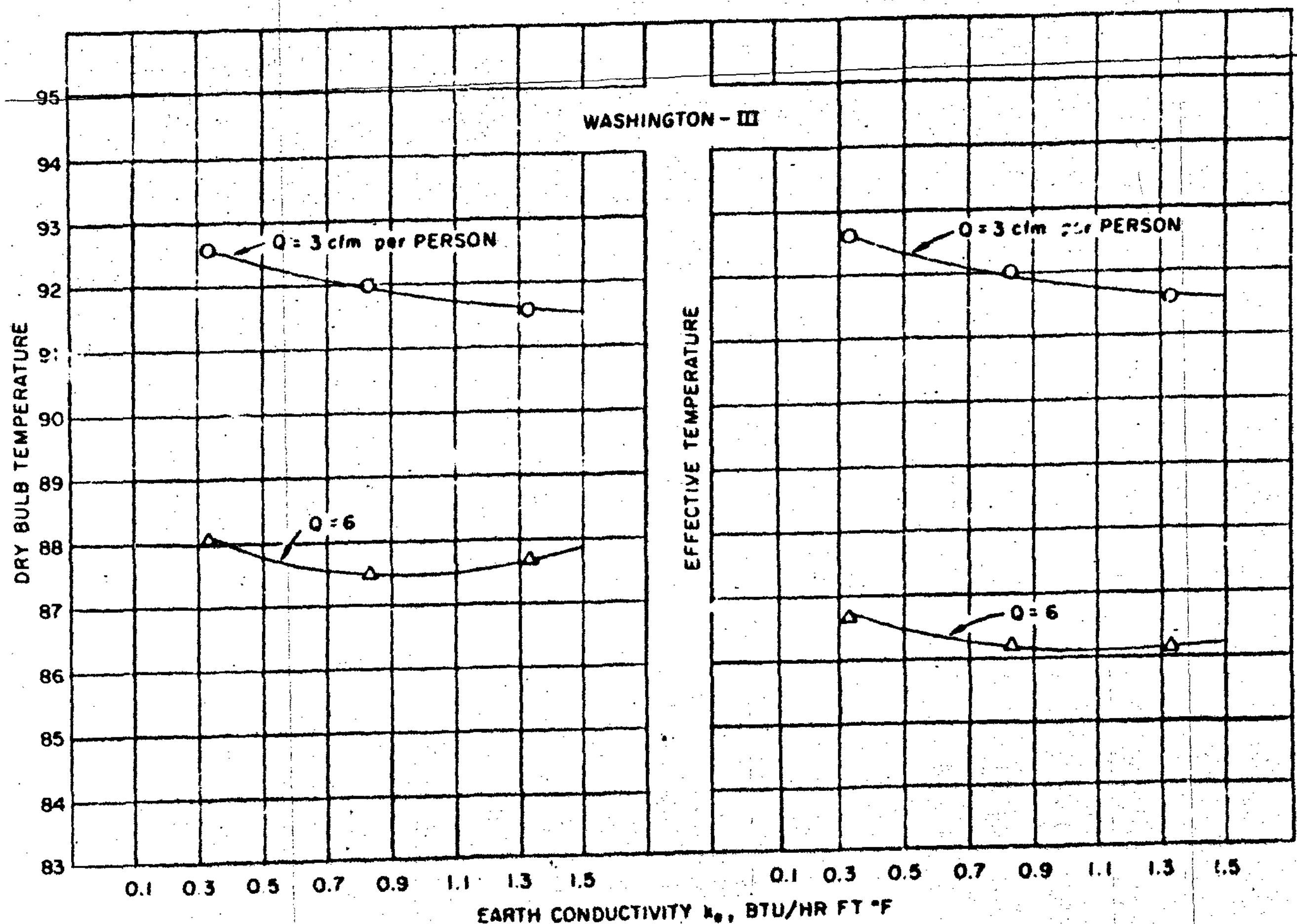
(1) Thermal Environment in Community Shelters (1963).[27]

(2) "A Generalized Computer Program to Analyze the Thermal Environment in Protective Structures" (1965).[24]

In both reports, the shelter ventilation problem is approached theoretically. The mathematical equations formulated consist, as in most theoretical studies of this problem, of coupled energy balance equations and heat transfer equations, and computers are chosen as means to obtaining solutions from these equations. The first solved the mathematical problem by means of an analog computer and the second with digital computer.

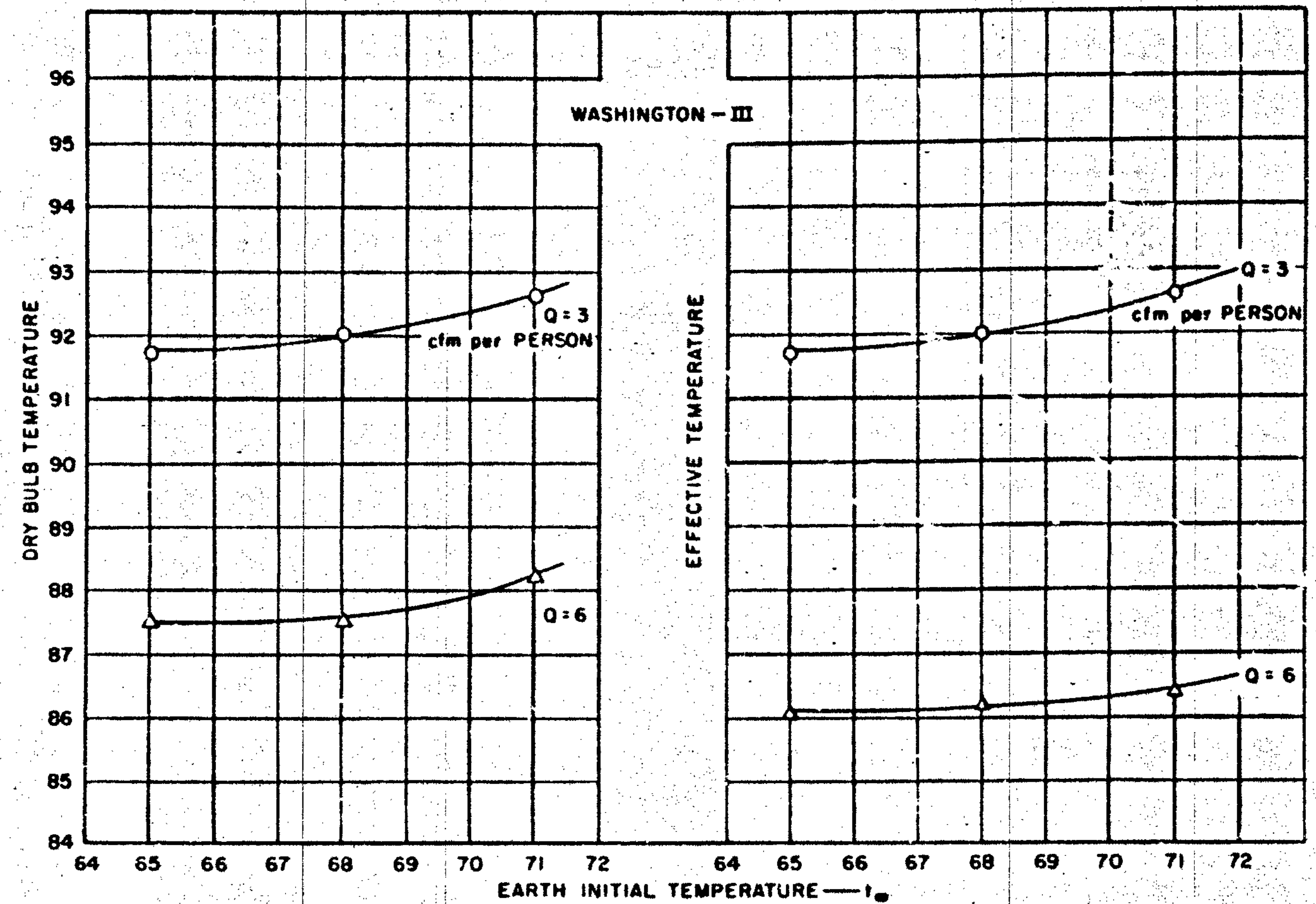
In Ref. 27, six types of shelters (described below), each of which could be a representative of a large number of designated shelters, were examined. This gross division of shelters into a few basic types is a very practical thought. (For further discussion of this approach, see Part 2 of Appendix F.)

In Ref. 27, a demonstration was afforded of the meaning of "parametric study." Such a study was made to determine the influences of various parameters upon the shelter temperatures. This was done by calculating the shelter temperature response as a function of a single varying parameter while holding the rest of the parameters constant. The figures in Ref. 27 show that the shelter DBT and SET varied no greater than one degree when either the earth conductivity was varied from 0.3 Btu/hr-ft-$^{\circ}$F to 1.15 Btu/hr-ft-$^{\circ}$F, or the earth initial temperature was varied from 65°F to 71°F. These figures are reproduced in Figs. C-1 through C-3. In Ref. 24, it was mentioned that the output from the digital computer was given in such a form that the SET was a function of



SOURCE: Ref 27

FIG. C-1 SHELTER TEMPERATURES AS A FUNCTION OF EARTH CONDUCTIVITY



SOURCE: Ref. 27

FIG. C-2 SHELTER TEMPERATURES AS A FUNCTION OF INITIAL EARTH TEMPERATURE

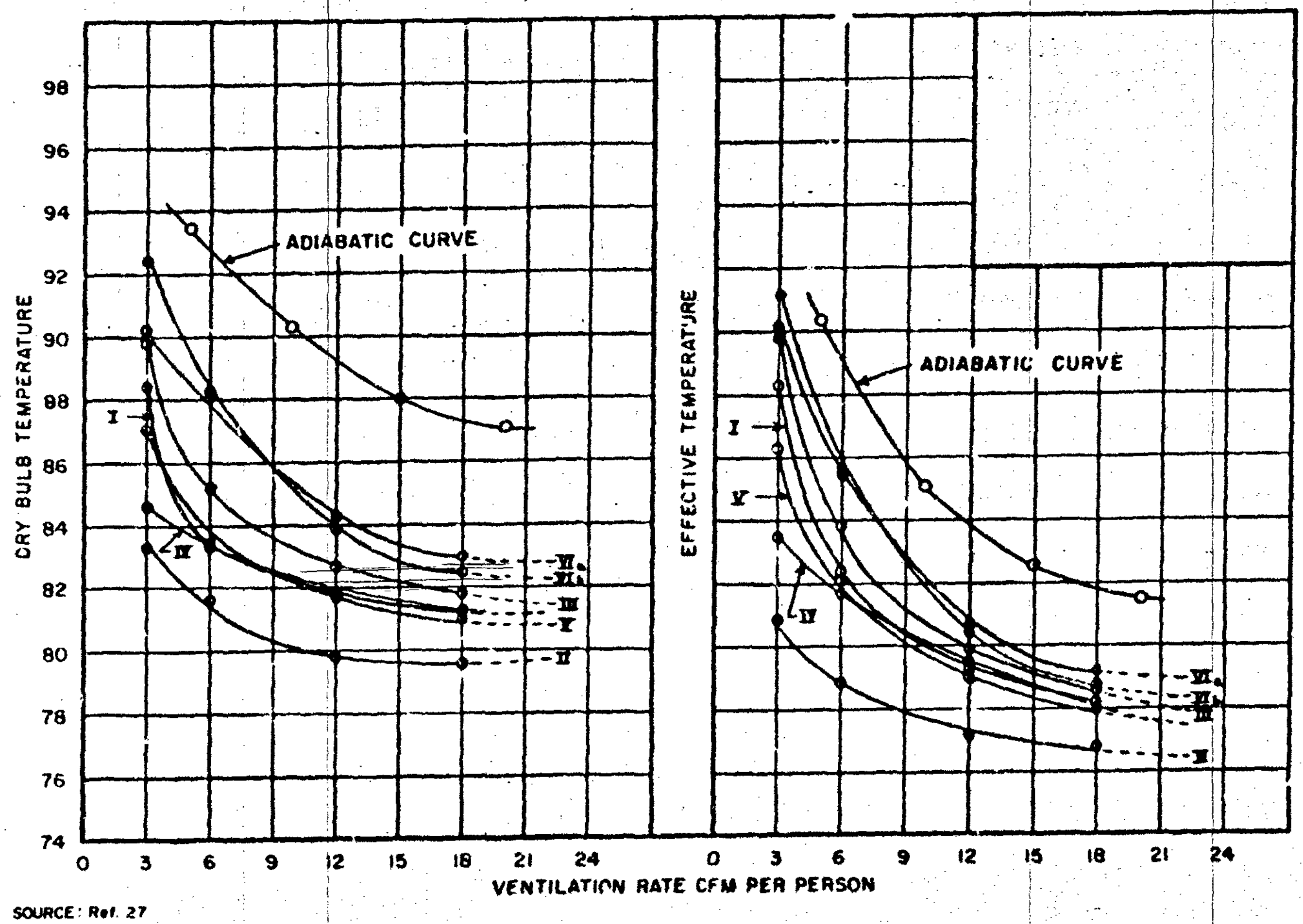
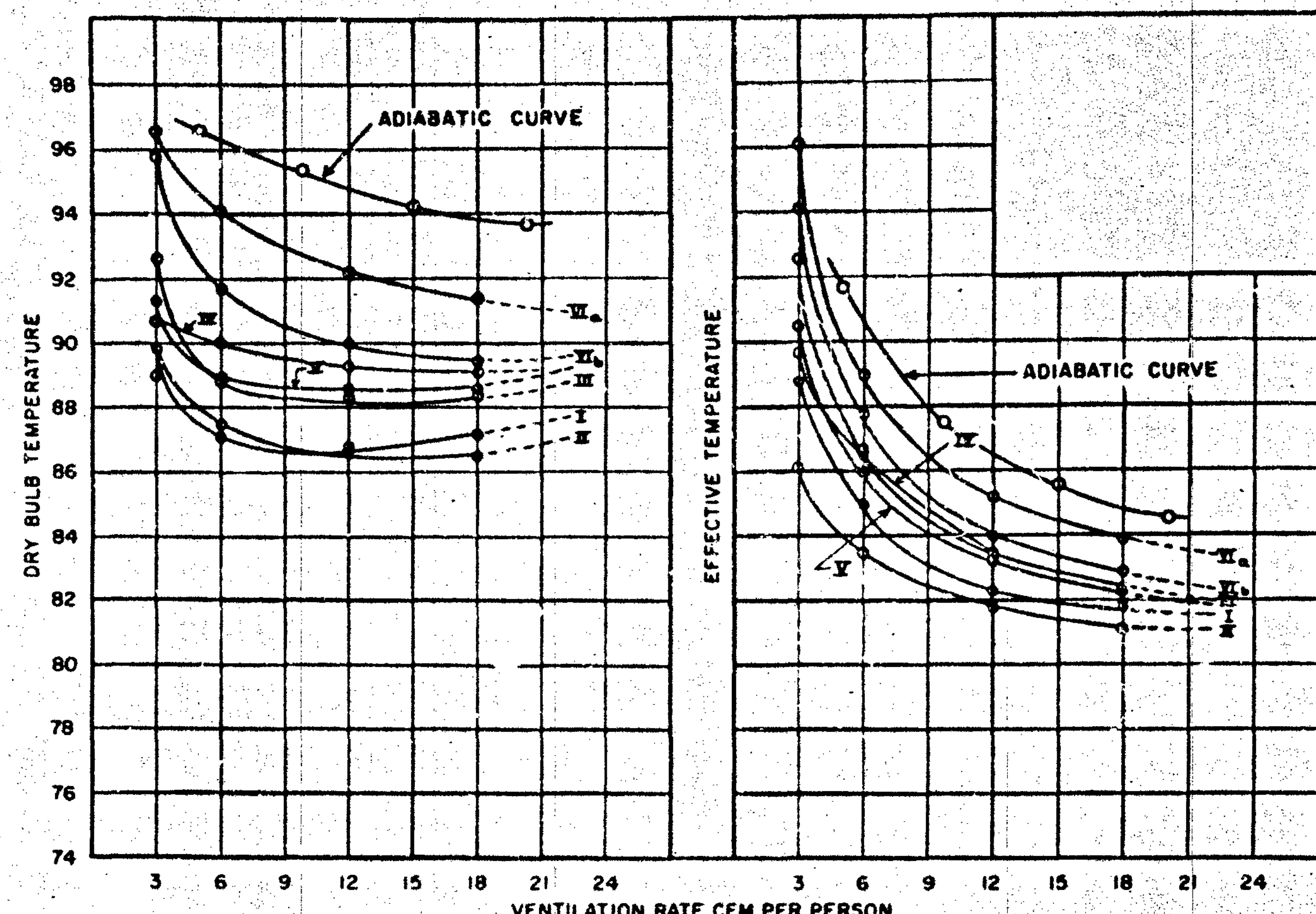


FIG. C-3 SHELTER TEMPERATURES AS A FUNCTION OF VENTILATION RATE FOR VARIOUS TYPES OF SHELTER CONSTRUCTION AND FOR ADIABATIC MODEL



SOURCE: Ref. 27

FIG. C-3 Continued

ventilation rate, air-cooling rate, and period of occupation. Although no explicit diagrams were provided in the report to show the effects of each of the three parameters, they nevertheless can be constructed.

A question is raised regarding Fig. C-1. In that figure, the Q = 6 curve shows that the shelter temperature has a minimum value at certain specific value of earth conductivity. It was not explained why the shelter temperature should have a minimum instead of being a monotonic function of earth conductivity.

In Ref. 27, a great portion of the analog computer results are presented in the form of diagrams plotting shelter dry-bulb temperature and ET against ventilation rate per person for various types of shelter configurations studied. A few of these figures are reproduced in Fig. C-3, with the adiabatic curves added. The Roman numerals tagged onto these figures signify the types of shelters:

- I Under-ground arch shelter
- II Above-ground rectangular parallel-piped shelter
- III Under-ground rectangular parallel-piped shelter
- IV High-rise rectangular parallel-piped shelter in the case of a building
- V High-rise rectangular parallel-piped shelter adjacent to ambients
- VIa Above-ground portion of a dual-level shelter
- VIb Under-ground portion of a dual-level shelter.

It is interesting to notice that the above-ground single-story shelter (Type II) is farther away from the adiabatic curve than the under-ground shelter (Types I and III). Here therefore, is an example that contradicts the general inference that above-ground shelters can normally be considered adiabatic in warm climate.

Although the formulation of the mathematical problem and the programs for the computers were competently done in both reports, the acquisition of the final numerical results still depends on the same

crucial problem that NBS faced, that is, what values of thermal coefficients should be used for a particular shelter. Some arbitrary average values of these coefficients were used in both reports.

5. Reports from Guy B. Panero, Inc.

Guy B. Panero, Inc., has carried out a total of eight shelter ventilation tests for OCD; each test was the subject of an interim report. The final report summarized these reports. All eight tests were essentially natural ventilation tests, and since in the present SRI report, emphasis is on a review of forced-ventilation tests, only a brief summary is given of the work done by Panero.

It is proper to mention that it is not the intention, in this report, to correlate the results of natural ventilation tests with those using forced ventilation. The natural ventilation tests, as we understand it, are continuing. It is generally believed that the mutual supplement of the natural and forced ventilation is a yet-unanswered question and deserves further research.

As mentioned earlier, all eight tests used essentially natural ventilation, occasionally supplemented by short periods of forced ventilation. The purpose of these supplementary periods of forced ventilation was chiefly to determine the corresponding ventilation rate obtainable from natural ventilation. A direct measurement of ventilation rate of natural ventilation is not possible.

All of the eight tests were carried out in New York City and vicinity. The test results are not readily applicable to similar types of buildings located in different parts of the country.

It was found that, for natural draft, crosswind ventilation is more efficient than updraft ventilation in an above-ground shelter. The term "crosswind" refers to that kind which utilizes the outdoor natural wind, permitting it to sweep across the shelter volume by opening up windows facing in appropriate directions. The term "up-draft ventilation" refers to air circulation caused by temperature differential, normally called the "stack" effect.

In most of the eight tests, whenever the natural ventilation alone was insufficient to keep the shelter effective temperature below 85°F, in 5 percent summer design day weather and at rated occupancy (10 ft^2/occ), the number of square feet of floor space per occupant was increased until natural ventilation alone was in fact sufficient to maintain a shelter effective temperature below 85°F.

One valuable discovery from these tests was that the "air exchange" between the shelter space and its surrounding rooms, the shelter space is normally represented by the central corridor areas, could be very effective in preventing the shelter effective temperature from rising too fast during the initial "button-up" stage.

Table C-I summarizes the eight tests.

6. U.S. Naval Radiological Defense Laboratory[31]

This was one of the earliest shelter environmental tests conducted under contract by OCD. Both Simoc and human occupancy tests involving 100 occupants were conducted in an underground standard Navy Ammunition Hut. The temperature of the shelter remained within comfortable limits during the 14-day occupancy. Simocs were first used as a precautionary measure. The Simocs used were improvised, using five-gallon paint pails, with nichrome heating wires mounted within. Moisture was provided by dripping water onto cotton flannel coverings, and water flow was regulated by a valve. The amount of water to be added was varied with the dry-bulb temperature of the room center.

The air flow rate, heat conducted through the walls and metabolic output, as well as the pertinent shelter temperatures, were measured or calculated.

Table C-I

SUMMARY OF PANERO VENTILATION TESTS

Test No.	Building Location of Test Site	Type of Test	Brief Description of Test Site	Concluding Remarks from the Test
1	John Adams House N.Y., N.Y.	C-W, U-D S-C Tests*	18th Floor Center Corridor Area	(1) Shelter can be considered adiabatic (2) Natural ventilation is sufficient to keep shelter ET below 85°F with N.Y.'s 5% summer design day weather (3) Crosswind ventilation is most efficient (4) S-C test gives U = 0.27§
2	40 Wall St. Bldg. N.Y., N.Y.	Summer, C-W, U-D, S-C Tests	17th Floor Center	(1) Shelter can be considered adiabatic (2) Natural ventilation alone unable to keep shelter ET below 85° with N.Y.'s 5% summer design day weather unless space allocation is increased to 16 ft^2/occ (3) U = 0.21
3	AMA Bldg. N.Y., N.Y.	Summer, C-W, U-D, A-E Tests†	13th Floor Central Core Area	(1) Shelter can be considered adiabatic (2) Natural ventilation alone unable to keep shelter ET below 85°F with N.Y.'s 5% summer design day weather unless space allocation is increased to 20 ft^2/occ (3) U = 0.30
4	Public School 115 N.Y., N.Y.	Summer, Natural Vent. Forced Vent. S-C Tests	Basement and 3rd Floor Corridor	(1) Above-ground shelter can be considered adiabatic. Basement estimated about 40% heat transmission through the boundary (2) Crosswind most efficient for above-ground, updraft for basement (3) Above-ground shelter ~~can~~ maintain 85°F eff. However, space allocation in the basement has to be 16 ft^2/occ in order to maintain 85°F eff. Both based on 5% summer design day weather.
5	Public School 21 N.Y., N.Y.	Summer, C-W, U-D, S-C, Forced Vent.	Basement and 2nd Floor Corridor	(1) Same as item (1) above (2) Above-ground shelter can be kept below 85° ET by natural ventilation assuming 10% summer design day weather (3) Forced ventilation at 11 cfm/occ is required for basement to be under 85 ET at 5% summer design day.
6	Home Basement Westchester Co., N.Y.	Summer, S-C, Nat. Vent. Forced Vent.	Basement of an un-attached 2-	(1) 36% of total heat load is lost through boundary (2) 15 ft^2/occ is necessary to keep shelter ET below 85°F with 5% summer design day using natural

	N.Y., N.Y.	Vent. Forced Vent. S-C Tests	Corridor	basement estimated about 40% heat transmission through the boundary (2) Crosswind most efficient for above-ground, updraft for basement (3) Above-ground shelter can maintain 85°F *eff.* However, space allocation in the basement has to be 16 ft^2/occ in order to maintain 85°F eff. Both based on 5% summer design day weather.
5	Public School 21 N.Y., N.Y.	Summer, C-W, U-D, S-C, Forced Vent.	Basement and 2nd Floor Corridor	(1) Same as item (1) above (2) Above-ground shelter can be kept below 85° ET by natural ventilation assuming 10% summer design day weather (3) Forced ventilation at 11 cfm/occ is required for basement to be under 85 ET at 5% summer design day.
6	Home Basement Westchester Co., N.Y.	Summer, S-C, Nat. Vent. Forced Vent. A.P.C.U.+ Tests	Basement of an un-attached 2-story house	(1) 36% of total heat load is lost through boundary (2) 15 ft^2/occ is necessary to keep shelter ET below 85°F with 5% summer design day using natural ventilation alone (3) U = 0.39
7	New Canaan Shelter Connecticut	Winter Nat.-Forced-Vent., No. Vent. Insulation Tests	Under-ground Shelter	(1) Shelter ET would be too low (between 40° and 50°) during winter season at rated occupancy (2) Paneling insulating material on the wall would increase shelter ET by 11°F
8	Vicentown Shelter, N.J.	Summer Nat. Vent. Forced Vent.	Under-ground Shelter	(1) Only 14% ~ 30% of total heat is lost through wall (2) 11 cfm/occ of forced ventilation is necessary to keep shelter ET below 85°F at 5% summer design day. (3) Shelter ET is greatly reduced if well-water is available. (Not actually available, a water-exchanger using ordinary water supply was tested)

*C-W = Crosswind, U-D = Updraft, S-C = Shelter Calibration (equivalent to no vent. test)

†A-E = Air Exchange Test

§U is defined by eq. $Q = UA\Delta T$, it has the unit of Btu/hour ft^2 °F

+Air pump and coil unit--a heat exchanger unit

B

Appendix D

PSYCHROMETRIC CRITERIA OF AMBIENT AIR AND RELATIONSHIP TO PHYSIOLOGICAL CRITERIA

For practically all fallout shelters the major portion of the thermal load generated in the shelter will be removed by the ventilating air in the summer months. In order properly to determine the minimum required ventilation rate (RVR) for maintaining survival conditions on a summer day, the design criteria of the ambient ventilating air for all geographical locations must be established. Various approaches have been presented for establishing the design outdoor condition of the air. One principal source of data would be the United States Weather Bureau (USWB), which makes available records of coincident hourly dry-bulb and wet-bulb temperatures for the principal cities of the U.S. The National Bureau of Standards (NBS) and General American Transportation Corp. (GATX) have presented discussions on various approaches to the determination of psychrometric criteria. Relevant portions from the article by Kusuda and Achenbach[20] and from the reports by GATX are discussed in the following sections, since the material deals directly with the development of the outdoor design temperature criteria that would be used in determining shelter ventilation requirements.

1. The Single-Point Criterion

In the single-point criterion method, a single psychrometric point is used as the outdoor air design criteria. This point is established by any two parameters on a psychrometric chart, such as the dry-bulb temperature (DBT) and wet-bulb temperature (WBT). The "design" WBT and DBT for the cooling load are listed independently for various cities in the ASHRAE Guide (Ref. 1, Chap. 27) and classified as 1 percent,

2-1/2 percent, and 5 percent design days.* These data represent the percentage of the four summer months during which it might be expected that the design temperature would be equalled or exceeded.

The National Bureau of Standards has illustrated one approach for determining the single-point criterion. The 1, 2-1/2, 5, and 10 percent values of noncoincident, separately listed DBT and WBT were taken from the ASHRAE Guide and the weather data of Army, Navy, and Air Force Manual and used as a basis. These data were, in the example, actually treated as coincident in order to compare the percentage of hours that the proposed design temperatures would be equalled or exceeded. Results for studies of data from three cities (Houston, Phoenix, and Minneapolis) are summarized in Table D-I and are based on a nine to ten year summer weather record. (A detailed table is included in the original paper by NBS.) Taking from the table the 5 percent criterion as an example, it is seen that when the 5 percent DBT and 5 percent WBT were used as coincident data, the percentages of excess hours† were 0.6, 0.2, and 1.7 percent for the three cities, respectively. The lower percentage values indicate that by assuming coincidence between the independent design DBT's and WBT's, the ventilation requirement computed would turn out to be overconservative (for an adiabatic shelter model).

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* The design DBT is emphasized in air conditioning problems, since the heat transfer from the outside surroundings into the building usually constitutes a greater part of the cooling load; excepted are such places of high occupant concentration as auditoriums and theaters. Since most of the ventilating air inside the building is normally recirculated and a minimum of outside air added for replenishment, the outside WBT is considered only in determining the load on the conditioning equipment. The indoor relative humidity is controlled by the apparatus dew point and reheaters if used. Thus the approach to this problem is different from that of the shelter ventilation problem.

† The term "excess hours" as used in this report is the total hours for which the assumed coincident WBT and DBT were equalled or exceeded over a ten-year period. This is in keeping with the definition in the ASHRAE Guide for summer design, which refers to the summer hours (%) "at or above" the design temperature of interest. NBS lists separately the number of hours that exactly equal and the number that exceed this criterion. The two categories must therefore be totalled in order to compare results with the ASHRAE design day.

Table D-I

SINGLE-POINT CRITERIA FOR THREE CITIES

Design Criterion	Houston, Texas (9 yr period, 26,343 hrs)			Phoenix, Arizona (10 yr period, 26,280 hrs)			Minneapolis, Minnesota (10 yr period, 26,280 hrs)		
	DBT, °F	WBT, °F	*Total Excess Hours in %	DBT, °F	WBT, °F	Total Excess Hours in %	DBT, °F	WBT, °F	Total Excess Hours in %
1% ASHRAE Guide									
1% DBT, 1% WBT	96	80	0.03	109	77	0	93	78	0.22
1% WBT w. most frequent DBT	90	80	0.34	103	77	0.07	92	78	0.26
2-1/2% ASHRAE Guide									
2-1/2% DBT, 2-1/2% WBT	94	80	0.15	107	76	0.03	90	76	0.62
2-1/2% WBT w. most frequent DBT	90	80	0.34	97	76	0.36	87	76	0.98
5% ASHRAE Guide									
5% DBT, 5% WBT	92	79	0.6	105	75	0.2	87	74	1.7
5% WBT w. most frequent DBT	89	79	0.94	97	75	1.2	90	74	3.1
10% ANAFM									
10% WBT	90	78	2.0	103	74	0.4	82	71	5.3
10% WBT w. most frequent DBT	86	78	3.7	98	74	2.6	75	71	8.0

* Excess hours refer to the sum of specific coincident hours plus excess coincident hours that are presented in the paper by Kusuda & Achenbach.

National Bureau of Standards has also pointed out that the shelter effective temperature (SET) is more sensitive to outdoor WBT than to the outdoor DBT in the region of 83° to 85° ET. Figure D-1 (courtesy of F. A. Allen) illustrates the effect of the DBT and WBT on the ET. On this basis, another possible single-point design criterion was presented. For the three example cities, the 1, 2.5, 5, and 10 percent WBT's were listed together with the DBT's that occurred most frequently with each respective WBT. The total excess hours expressed in percent using weather data of the three cities are also presented in Table D-I. It is seen that this method is slightly more realistic than the method of using the combination of the independent dry-bulb and wet-bulb design temperatures, but there are still considerable inconsistencies in the excess hour percentages depending on the location of the cities, for example, a 5 percent wet-bulb with the most frequent dry-bulb design criteria in Table D-I shows 0.94 percent, 1.2 percent, 3.1 percent for Houston, Phoenix, and Minneapolis, respectively. Other possible design criteria--using parameters such as maximum temperature, maximum daily average and maximum weekly average--were analyzed and found to possess similar weaknesses.

The single psychrometric point criterion assumes, of course, a steady-state condition of the ventilating air and would be a convenient one. If such a criterion could be determined, a chart such as shown in Fig. D-3 or D-4, below, could be used to determine shelter ventilation for an adiabatic shelter. However, to date, it was not possible to propose a system that would determine the single-point criterion in which the "percent design day" value would be consistent to all parts of the U.S. There does not appear to be any orderly manner in which to establish the single psychrometric point criterion.

In spite of this difficulty, the possibility of the use of the single-point criterion should not be eliminated, since the percent design day data are so readily available. With the assignment of proper correction factors, the single-point method would be applied where independent calculations of ventilation rates in special locations may be needed and where adequacy factor curves (discussed below) are not available.

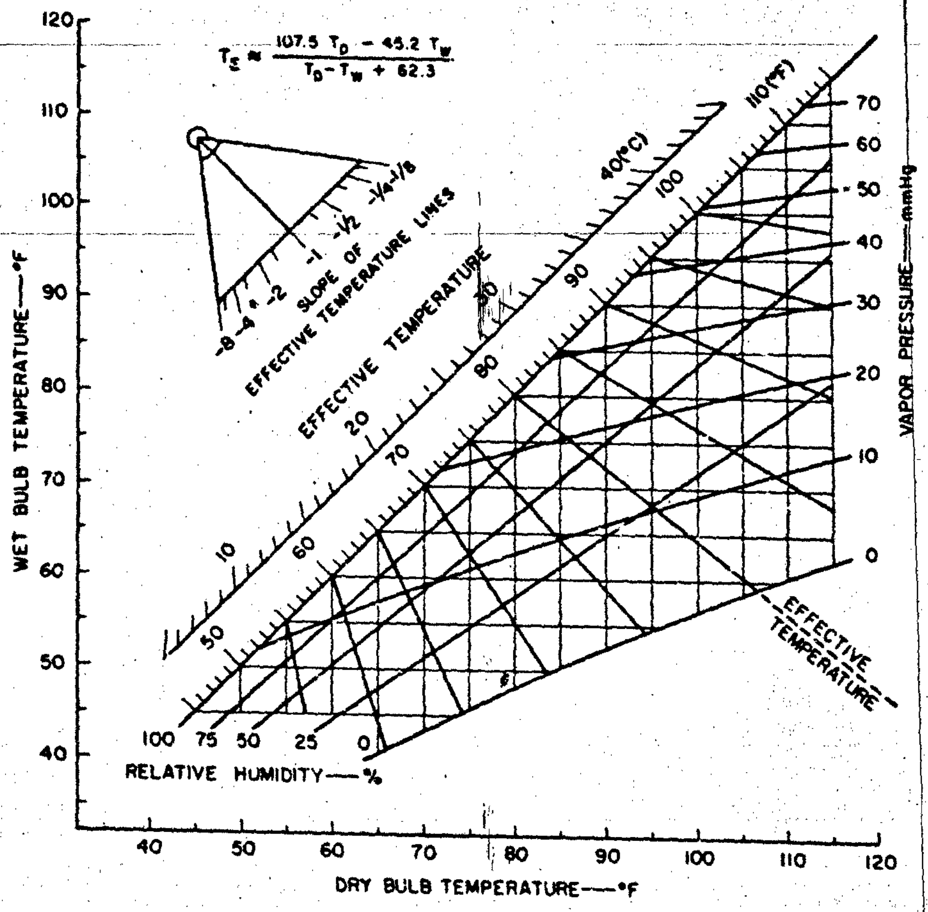

FIG. D-1 LINEAR APPROXIMATION OF STILL AIR EFFECTIVE TEMPERATURE

2. Adequacy Factor

The ventilation adequacy factor, or simply the adequacy factor (AF), is the proportion of the total time (e.g., month, year, decade, etc.) during which a shelter condition may be expected to be maintained at or below a given ET with a given ventilation rate. The adequacy factor is a probability factor of climate occurrence developed from coincident weather data and may be expressed as a decimal or a percentage. The authors generally agree on the recommendations of NBS and GATX for acceptance of the adequacy factor method of determining the basic ventilation rate.

a. Development of Adequacy Factor--Weather Matrix

Adequacy factors based on the hourly data are derived from the hourly coincident DBT and WBT records (such as those of the National Weather Record Center of the U.S. Weather Bureau). The process of determining the adequacy factor can be seen in a matrix listing the frequencies of occurrence of the coincident DBT and WBT. In the paper by Kusuda and Achenbach,[21] a matrix (Fig. D-2) was developed as an illustration using the coincident annual weather data for Houston, Texas. In this figure,

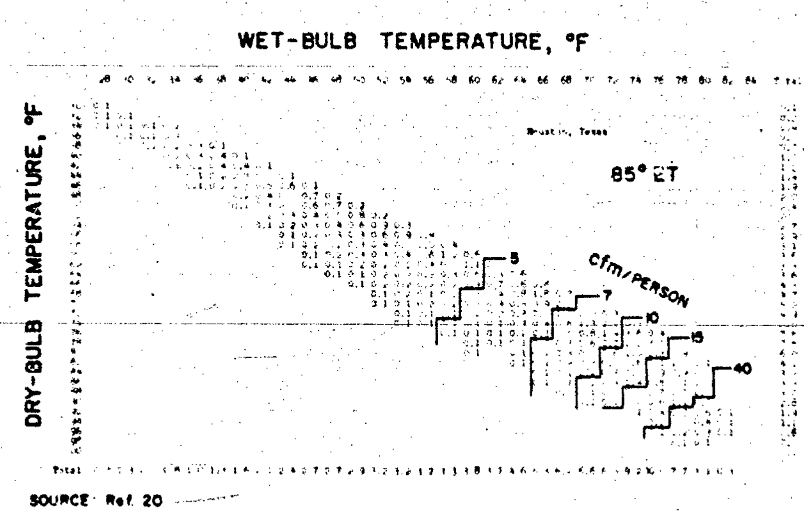

FIG. D-2 MATRIX PERCENTAGE FREQUENCY TABULATION OF COINCIDENT DRY-BULB AND WET-BULB TEMPERATURES, HOUSTON, TEXAS. Isoventilation rate boundaries for SET of 85° F indicated by lines

the frequency of occurrence for each coincident combination of DBT and WBT is expressed in the matrix as percentage values of the total hours comprising the year. For each of the combinations of outdoor DBT and WBT shown on the matrix, a required ventilation rate (RVR) in cfm per person to maintain a certain SET was determined, based on an adiabatic model and a shelter load of 400 Btu/hour per person. Thus lines connecting the points of equal ventilation on the matrix would represent isoventilation-rate lines. It is apparent from Fig. D-2 that, for a specific ventilation rate, air at many combinations of DBT and WBT is able to maintain a specific SET (85°F in this case). In Fig. D-3, which was developed by GATX, isoventilation lines are shown on a psychrometric chart. Each isoventilation line on Fig. D-3 defines the RVR of any combination of ventilating air DBT and WBT required to maintain a SET of 85°F. (Figure D-4 shows ventilation required for maintaining 82°F ET.) The 85°F ET line on Fig. D-3 (and the 82°F ET line on Fig. D-4) would represent an isoventilation line of an infinite ventilation rate. (More accurate charts which would supercede charts D-3 and D-4 are being developed.)

The isoventilation lines on the matrix (Fig. D-2) were actually reproduced from the isoventilation lines originally developed on the psychrometric chart. In this particular matrix, by totalling all the individual percentage figures lying on the upper left-hand side of a given isoventilation rate line, the AF is obtained for that specific ventilation rate which would maintain a certain SET. (A different set of isoventilation lines would be drawn for different SET criteria on the same matrix.) In Fig. D-2, as an example, the sum of all percentages to the upper left of the 7-cfm per person line would indicate a percentage of hours (adequacy factor or AF) for which the 7-cfm rate would maintain a SET of 85°F or below.

Thus, a criterion is developed for determining ventilation rates whereby it is possible to establish a specific adequacy factor applicable to all parts of the country in which coincident weather data are available.

General American Transportation Corporation has recently completed weather studies of 91 principal population centers in the U.S., and based on this information, have prepared the following information:

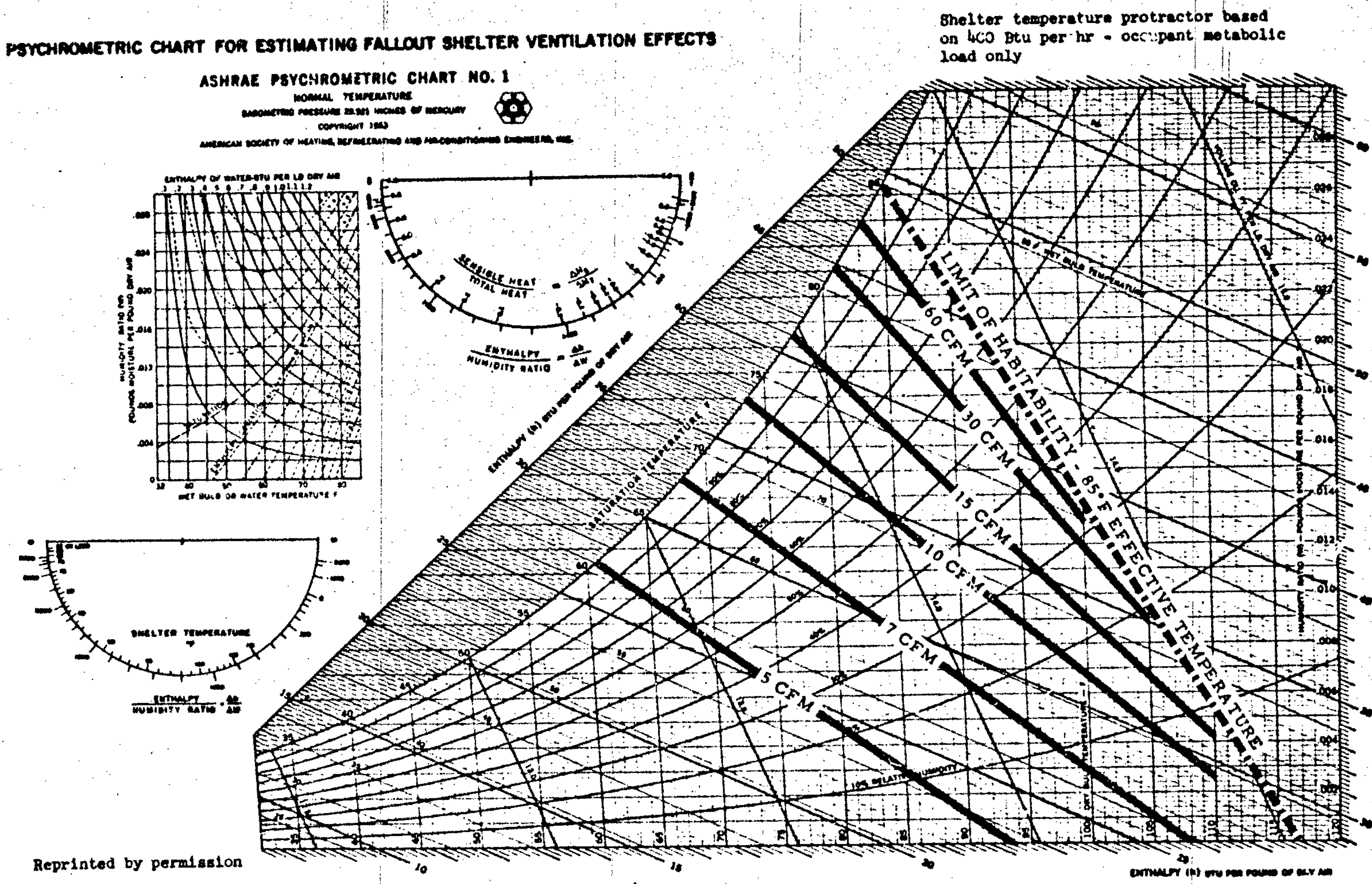

FIG. D-3 ISOVENTILATION RATES FOR COMBINATIONS OF DBT AND WBT REQUIRED TO MAINTAIN SET OF 85° F

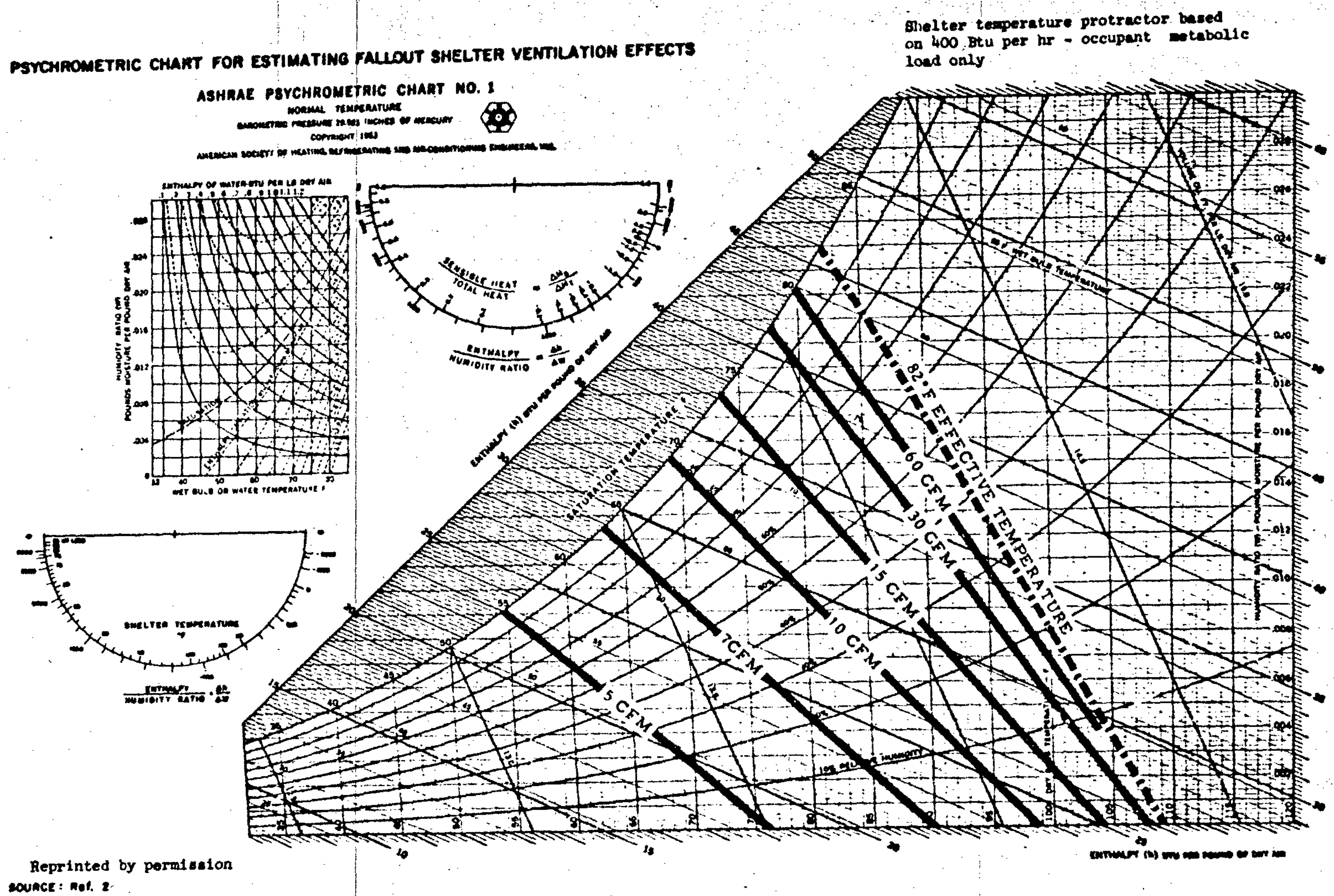

FIG. D-4 ISOVENTILATION RATES FOR COMBINATIONS OF DBT AND WBT REQUIRED TO MAINTAIN SET OF 82° F

(1) Complete tables of AF as a function of RVR per occupant, from 3 cfm to infinity in increments of 1 cfm, and for ET from 75°F through 90°F, compiled for each of the 91 cities.

(2) Tables of RVR per occupant as a function of AF in increments of 1 percent, for ET from 75°F through 90°F, compiled for each of the 91 cities.

(3) Curves of AF as a function at ventilation rate for a family of ET from 75°F through 90°F, compiled for the 91 cities.

(4) Matrices of hourly frequencies of coincident hourly DBT and WBT, based on a 10-year weather bureau record, and compiled for each of the 91 cities.

In the matrix developed by GATX [Item (4) above], a ten-year hourly weather record was used for each city. As an example, the matrix for San Antonio, Texas is reproduced in Fig. D-5, and covers the weather record for the period of September 1949 through August 1959. The frequency of occurrences of each coincident DBT and WBT are tabulated in number of hours, the total hours constituting a 10-year period (87,648 hours). Because the "adequacy factor versus ventilation rate" information is based on a long-term weather record, the information can be readily used as that representing a typical year.

The curves of AF as a function of RVR [Item (3) above] were prepared from data extracted from the matrices. In Fig. D-6 are shown curves of AF as a function of ventilation rate for eight of the cities, representing a portion of the 91 sets of curves that were prepared by GATX. These are based on the hourly weather data.

b. Adequacy Factor Based on Daily Average Temperature Data

The possible application of the daily average temperature was studied intensively by GATX. In their several shelter experiments, it was observed that, in general, the SET did not vary more than ±2°F from the average during any one day, even with a relatively large diurnal fluctuation of the ambient temperature. Because of this relatively small variation, the determination of the shelter ventilation rates based on the shelter daily average effective temperature appeared feasible. The analysis of data taken from shelter experiments, some of which were conducted for 14 days, indicated that there was close agreement between the

TEMPERATURE DISTRIBUTION OF

12911 – SAN ANTONIO, TEXAS – (SEPTEMB

WET BULB TEMPERA

DRY BULB TEMPERATURE

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
31	529																											
32	98	11																										
33	105	27	7																									
34	109	45	28	9																								
35	105	62	34	39	9																							
36	32	30	36	35	30	11																						
37	59	53	41	44	33	38	22																					
38	42	46	47	59	70	54	36	27																				
39	12	32	47	50	68	43	64	42	39																			
40	13	29	35	59	94	77	65	68	81	62																		
41	8	24	19	46	50	62	73	55	81	88	35																	
42	1	9	21	36	52	85	81	77	81	77	77	64																
43		5	18	27	57	53	90	71	81	76	55	90	51															
44			5	26	36	70	60	79	78	106	81	68	73	50														
45		2	4	17	29	44	92	93	80	128	91	71	74	74	68													
46			2	7	11	25	47	68	72	81	79	83	56	63	78	65												
47				1	11	12	58	70	78	84	95	80	64	64	109	92	59											
48				1	3	12	34	58	63	82	68	83	83	86	75	93	92	77										
49					2	7	17	38	47	70	74	100	90	72	76	68	76	126	81									
50					1	1	10	28	46	100	97	119	112	100	99	89	96	137	144	98								
51						1	2	13	19	61	65	70	88	80	99	71	79	84	93	131	55							
52							1	7	19	51	66	90	94	74	106	70	102	78	97	121	98	67						
53								5	13	29	51	60	91	92	79	82	66	82	92	126	131	118	69					
54								1	4	20	29	63	74	81	108	79	83	89	72	101	111	110	127	86				
55										15	30	52	59	91	108	114	103	112	83	120	89	138	137	137	120			
56										4	21	23	42	53	74	85	78	61	78	96	71	82	73	88	128	85		
57										3	7	21	42	44	72	78	107	81	69	78	62	68	91	105	136	107	109	
58											6	24	19	37	81	78	94	75	78	107	80	73	80	101	131	154	165	143
59											1	4	14	32	54	46	67	83	61	77	81	58	74	81	101	117	138	144
60											1	2	8	30	47	62	64	91	80	109	87	87	80	97	100	116	187	209
61												1	9	10	24	42	45	87	40	71	70	59	49	80	79	77	89	111
62												1	2	4	31	39	54	66	57	78	65	85	62	56	60	81	73	98
63														7	20	26	43	51	45	69	49	71	63	82	85	58	89	97
64														1	8	28	34	52	50	63	53	48	75	50	51	57	53	64
65														1	5	23	28	57	68	69	65	88	57	64	74	53	84	69
66																8	16	30	29	51	56	47	50	67	49	42	44	55
67															1	3	10	9	31	31	48	38	48	48	34	37	85	61
68																1	2	16	25	45	50	40	54	56	53	53	45	56
69																1	5	7	21	34	28	31	37	37	47	49	54	42
70																	1	5	18	29	38	54	48	45	67	60	63	52
71																		3	6	11	18	40	33	25	47	29	36	40
72																		2	6	18	16	30	45	24	45	40	51	41
73																			1	8	10	28	18	24	31	28	41	29
74																		1	2	8	6	18	24	36	25	35	29	30
75																			1		5	8	14	31	38	28	34	39
76																			1	1	8	8	11	13	16	24	25	29
77																					1	4	18	18	18	21	24	26
78																					3	3	11	11	16	18	16	19
79																						2	4	3	14	30	23	27
80																						2	1	6	11	13	15	29
81																							4		5	5	16	14
82																							1		1	5	7	15
83																								1	7	4	3	5
84																								1	3	3	7	1
85																									2	3	6	1
86																									1	1	3	2
87																										1	2	3
88																												
89																												2
90																											1	1
91																												
92																												
93																												
94																												
95																												
96																												
97																												
98																												
99																												
100																												
101																												
102																												
103																												
104																												
105																												
106																												
107																												

TOTAL NUMBER OF GOOD HOURLY RECORDS = 87,540

TOTAL NUMBER OF BAD HOURLY RECORDS = 108

A

DISTRIBUTION OF HOURLY VALUES

:XAS – (SEPTEMBER 1949 – AUGUST 1959)

T BULB TEMPERATURE

54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
86																													
137	120																												
88	128	85																											
105	136	107	105																										
101	131	154	166	143																									
81	101	117	138	144	90																								
57	100	116	187	209	178	119																							
68	79	77	89	111	136	171	112																						
56	60	81	73	98	123	193	193	147																					
62	85	56	85	97	73	154	204	276	115																				
50	51	57	53	64	83	94	158	295	228	106																			
64	74	53	64	69	87	119	120	206	325	324	169																		
67	49	42	44	55	48	77	94	130	195	304	314	67																	
48	64	37	65	61	63	77	78	81	146	237	332	252	71																
56	53	53	45	56	53	70	84	99	121	178	309	332	252	68															
37	47	45	54	42	51	46	52	83	82	120	208	283	353	181	55														
45	67	60	63	52	45	78	68	84	97	93	200	215	303	353	203	72													
25	47	29	36	40	39	47	41	64	66	83	111	120	173	241	235	177	54												
24	45	40	51	41	43	58	51	85	68	93	127	131	162	238	272	290	222	51											
24	31	28	41	29	35	49	36	59	69	67	121	136	140	205	223	359	334	274	50										
36	25	35	29	30	33	31	24	57	65	78	83	84	115	180	163	301	345	424	289	52									
31	36	28	34	39	26	42	35	56	58	57	110	111	114	168	167	277	324	553	562	290	64								
13	16	24	25	29	23	38	23	48	52	57	65	66	97	110	123	199	245	358	496	380	153	10							
18	18	21	24	25	24	31	33	45	48	46	65	53	93	112	122	193	199	317	490	457	249	39							
11	16	18	16	19	22	29	30	35	39	47	64	74	85	102	141	205	179	290	382	455	347	87	8	1					
3	14	30	23	27	29	27	29	39	27	32	48	61	63	96	114	167	156	225	291	354	316	99	16						
6	11	13	19	29	28	24	27	33	40	34	50	84	72	108	121	198	161	227	312	368	322	132	32	5	2	1			
	5	5	16	14	23	9	11	22	20	22	38	53	60	95	94	123	120	154	195	276	206	90	26	3	1				
	1	5	7	15	18	15	22	19	35	20	27	37	54	90	82	107	137	169	234	226	223	94	22	18	9				
1	7	4	3	6	7	15	17	23	24	24	40	33	45	67	89	102	98	160	214	241	205	88	31	14	1				
1	3	3	7	1	10	18	10	17	18	22	29	34	61	64	60	111	107	142	193	227	210	91	25	6	3		1		
	2	3	6	1	6	9	10	14	15	34	33	37	42	55	60	115	119	179	228	270	289	102	42	24	4	2			
	1	1	3	2	8	13	8	9	11	19	19	21	34	46	45	91	78	120	174	189	207	96	39	16	4	2	1		
		1	2	3	4	9	10	8	14	15	17	25	29	30	42	76	89	125	194	202	177	111	64	16	8				
					2	2	10	4	8	15	21	14	25	30	44	69	69	126	173	215	210	98	43	22	8	3	2		
				2	1	4	3	8	8	15	11	13	18	23	30	40	68	103	153	201	188	98	37	17	5	4	2		
			1	1			4	2	4	7	13	12	17	27	35	60	65	124	192	235	234	136	55	33	8	6		1	
					1	1	3	2		2	10	8	8	12	26	29	49	111	145	175	207	74	39	15	18	2	1	1	
							2	1	2	2	4	7	3	17	23	46	57	93	149	182	185	91	34	20	8	1			
							1	2	2	1		5	7	10	29	29	78	81	156	161	165	84	39	18	4	2			2
						1	1	1	2			1	6	3	18	38	41	74	141	161	153	80	33	13	3	2		1	1
						1		2	1				2	7	15	32	58	91	153	150	145	71	31	9	3	3	2	2	
									1		1		1	3	3	28	34	80	72	121	89	55	26	4	1				
								1	1	1			3	6	4	15	38	64	83	96	97	40	19	4					
								1					2	3	8	8	13	50	57	72	88	30	12	1	1				
														4	2	12	14	30	32	41	38	21	3	1					
													1	2	3	8	7	13	28	30	32	12	5						
														1	4	4	5	3	6	12	9	2	5	1					
																	2	2	3	6	7	2	2	1					
																1	4	1	4	2	2								
																	2	1	1	1	1	1							
																			1										
																			1										
																			1										

FIG. D-5 MATRIX OF HOURLY FREQUENCY OF COINCIDENT DBT AND WBT FOR SAN ANTONIO, TEXAS

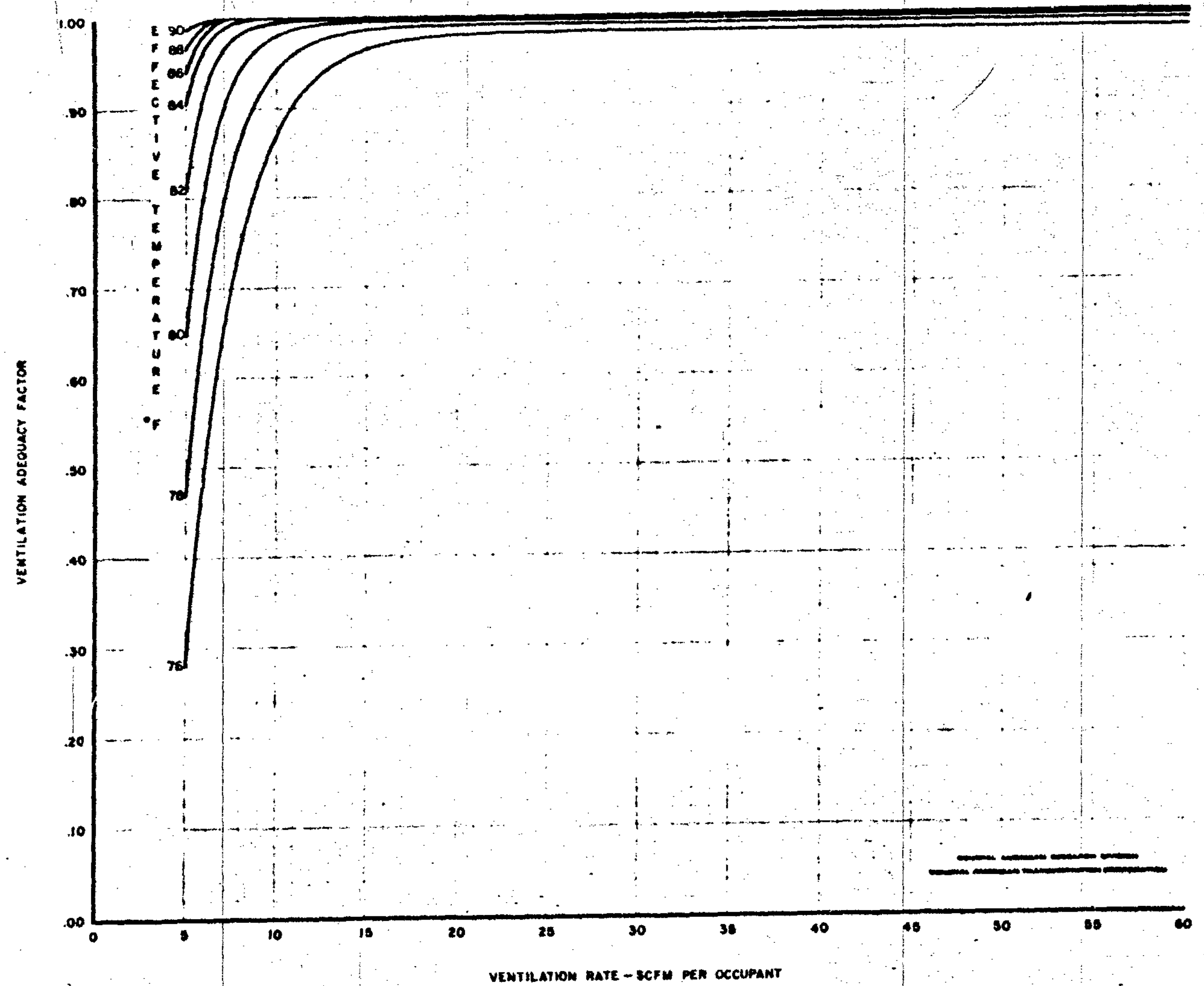

FIG. D-6 ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(a) Seattle, Washington

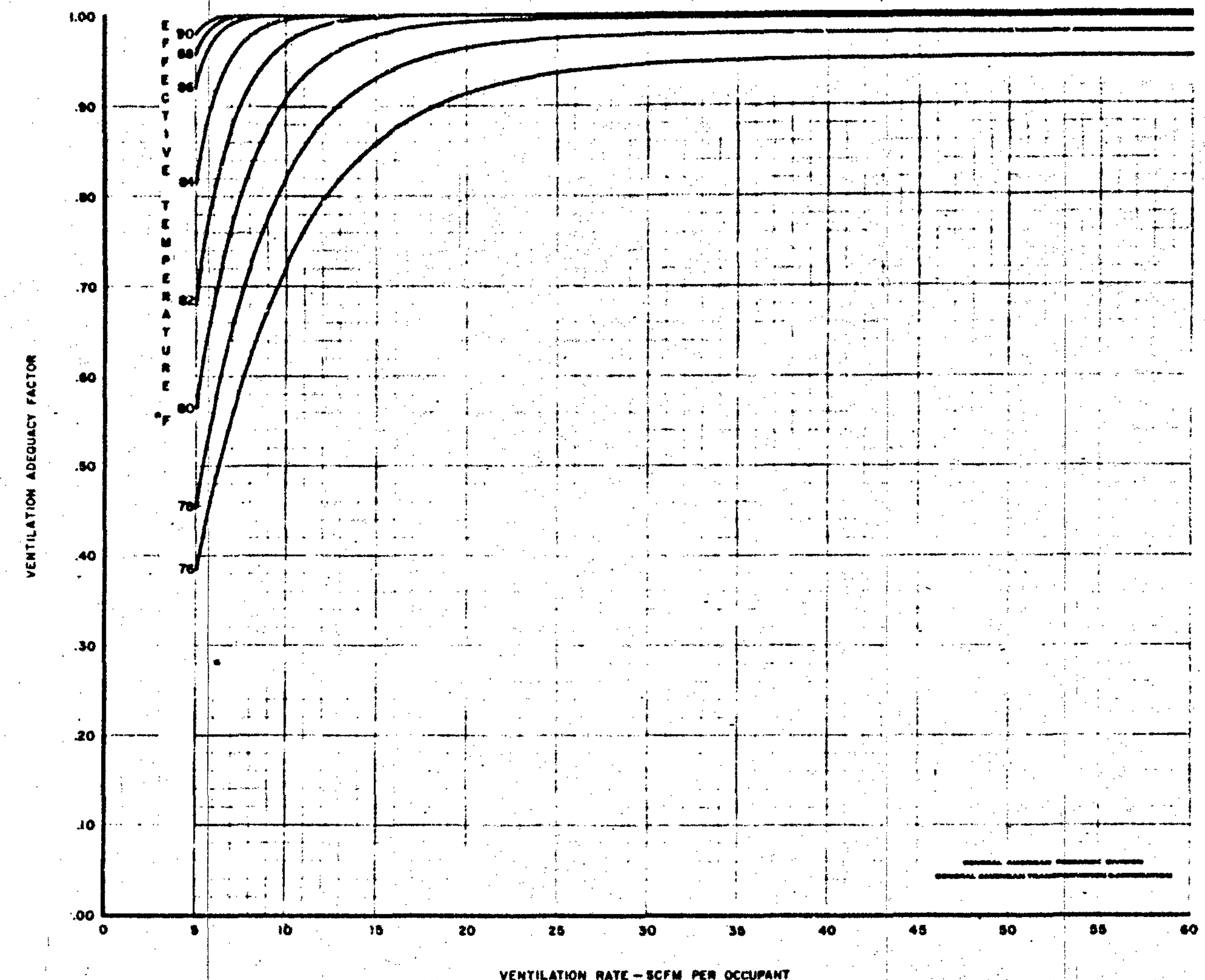

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(b) Denver, Colorado

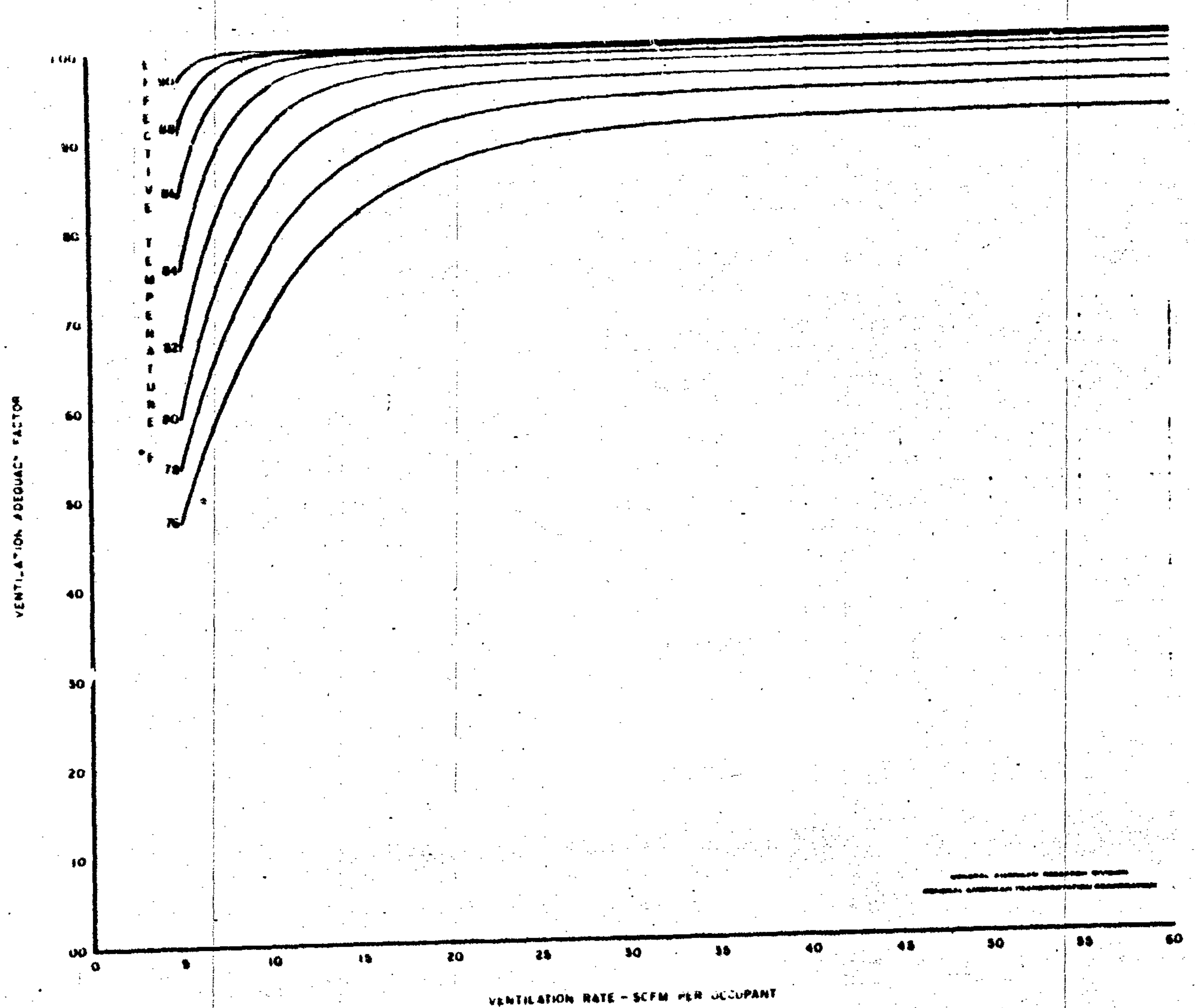

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(c) Minneapolis, Minnesota

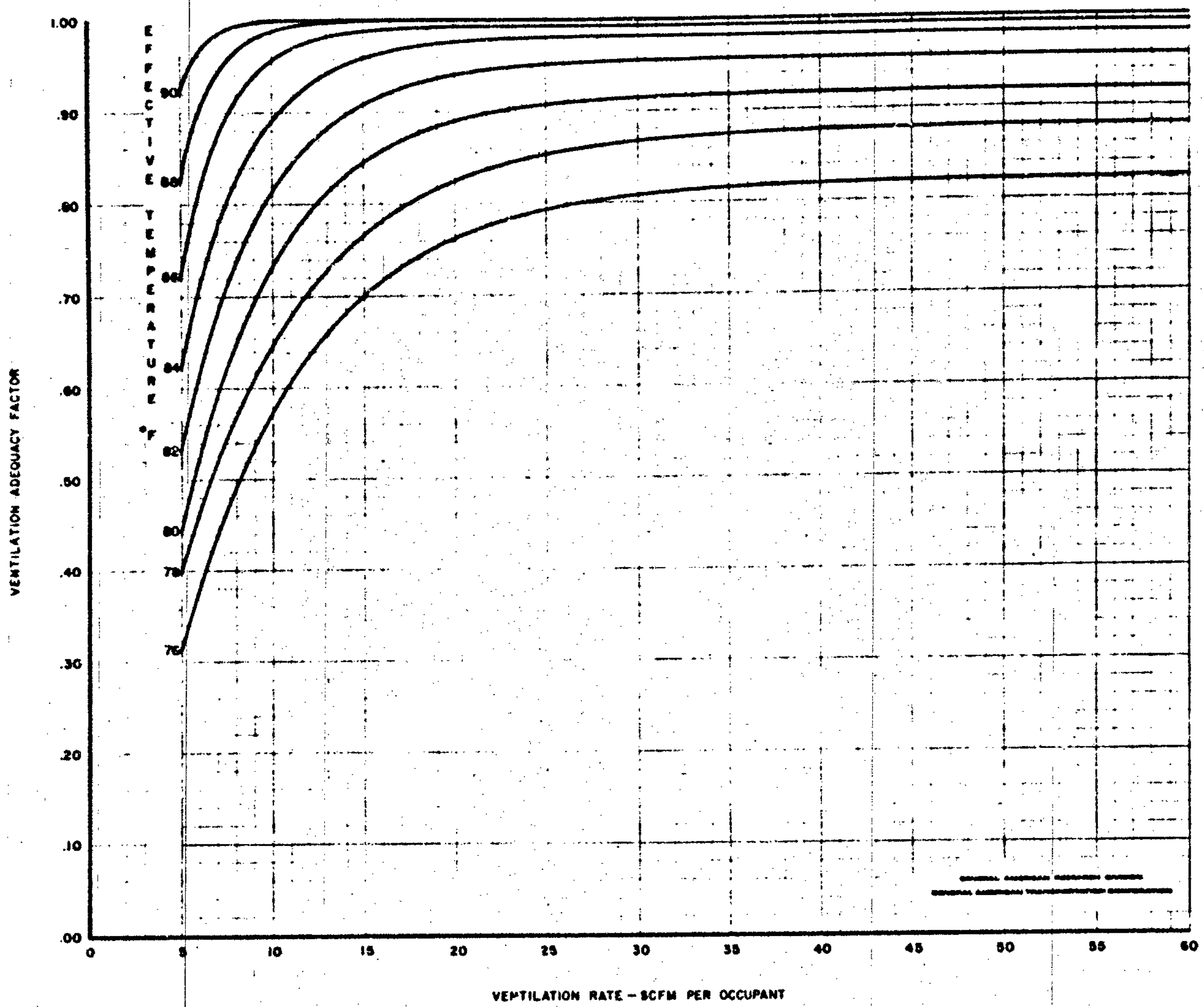

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(d) Washington, D.C.

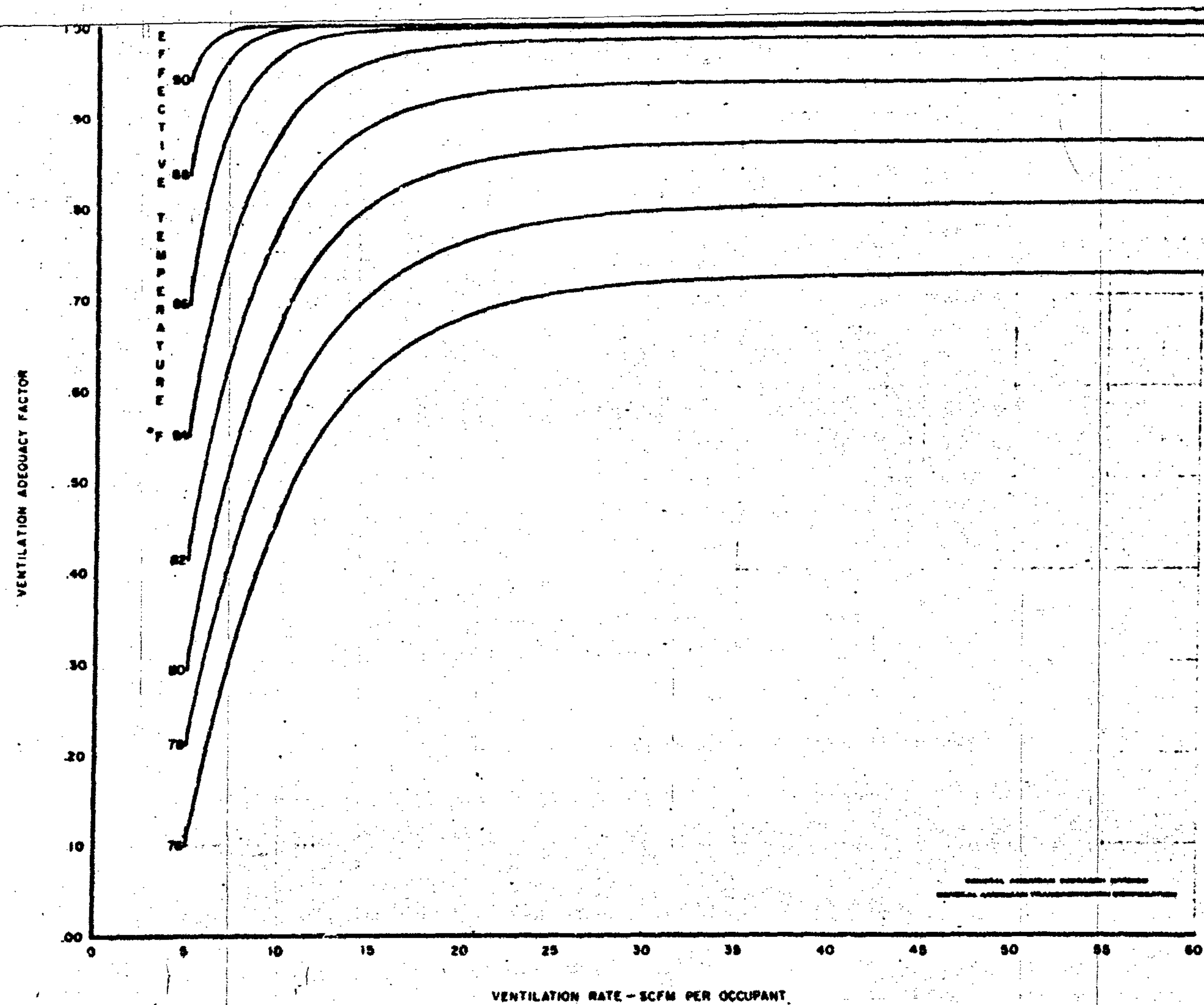

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(e) Tucson, Arizona

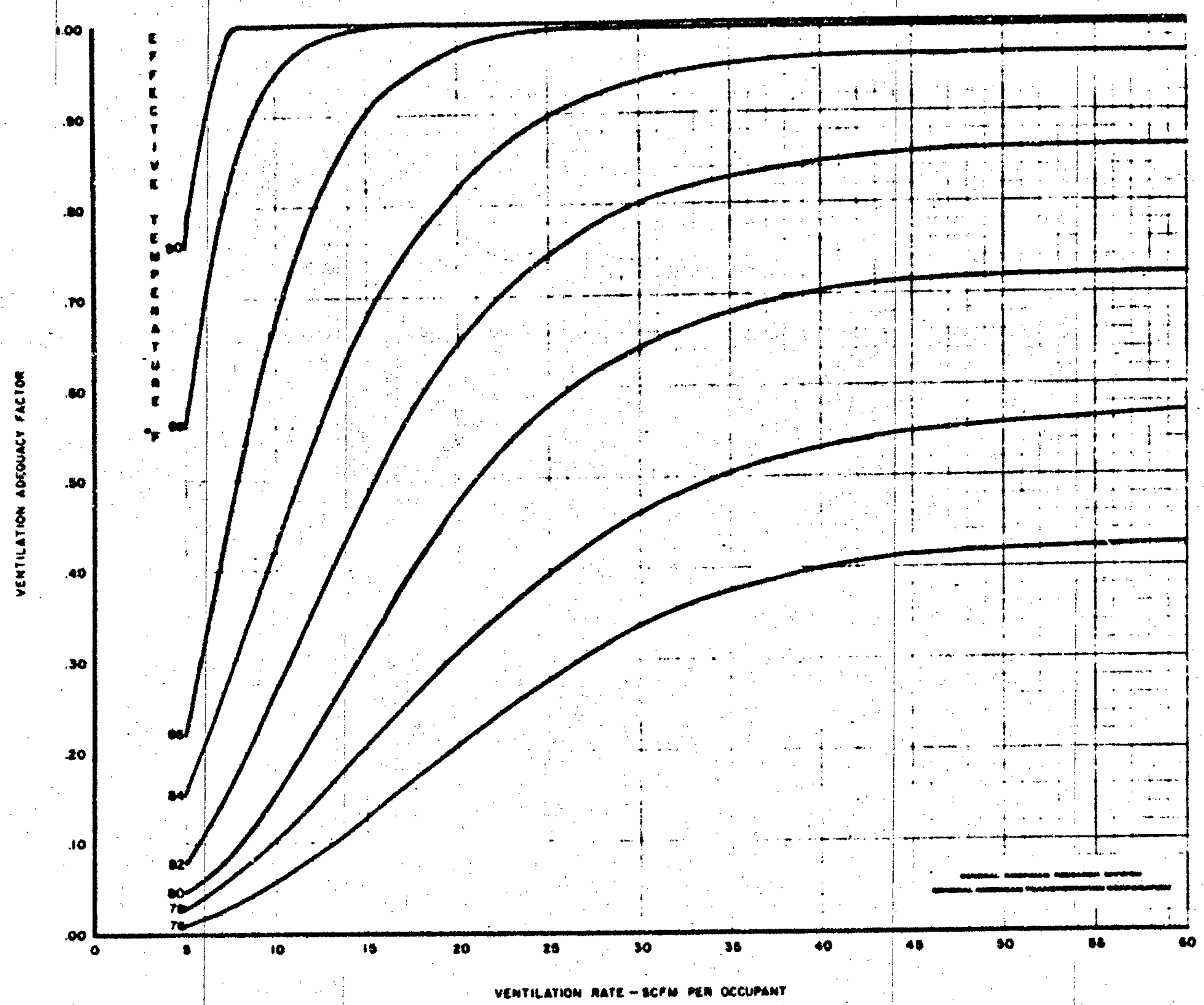

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(f) Miami, Florida

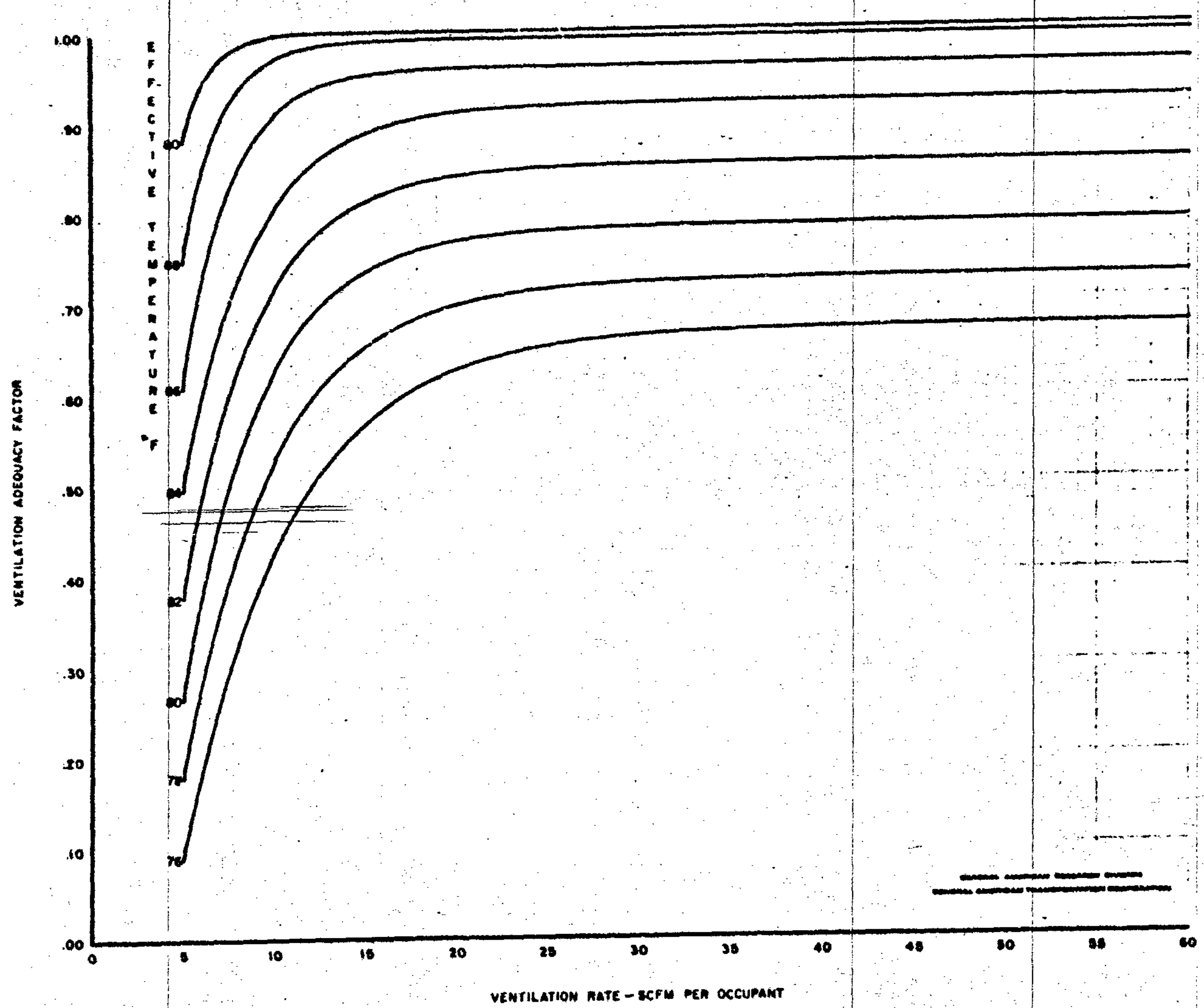

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(g) Phoenix, Arizona

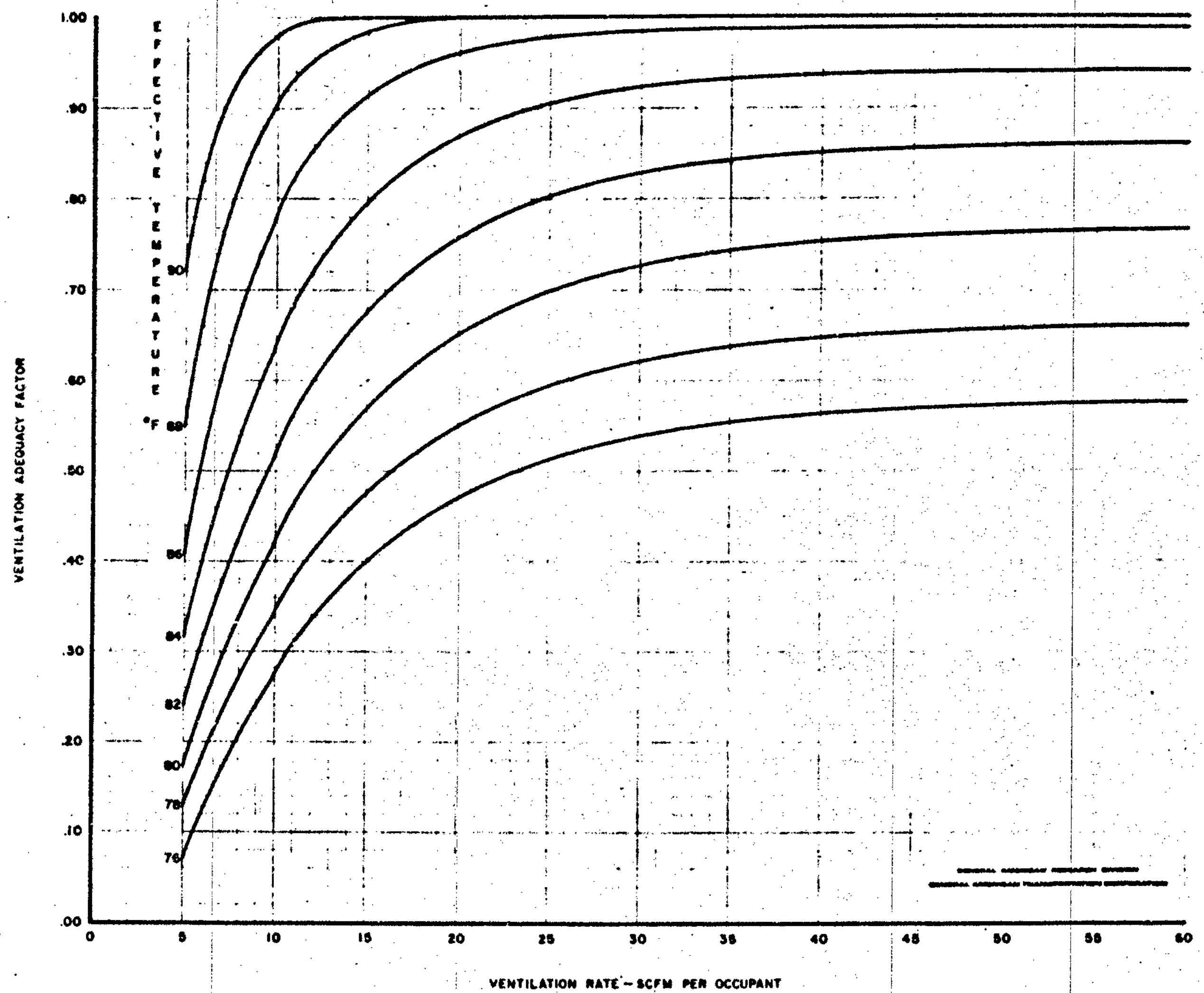

FIG. D-6 (Cont.) ADEQUACY FACTOR CURVES BASED ON HOURLY DATA
(h) Houston, Texas

time-average values of the transient analysis and steady-state analysis using daily average data (see Sec. X-D). An obvious advantage of the daily average data is the reduced quantity of data used compared to the hourly data.

Based on the above reasons, GATX developed AF curves using daily average temperature data. In this case, daily average DBT and WBT are used, and the frequencies of occurrence in number of days are tabulated in a matrix. The ventilation rates required for each of the coincident sets are determined similarly as in the hourly data mentioned in Part a, above. The ventilation AF using the daily average data is, therefore, the proportion of the expected number of days out of the total number of days per year, that a certain ventilation rate will maintain a certain daily average SET or less.

Adequacy factor/ventilation rate curves based on the daily average data are shown in Fig. D-7. These are curves of the same eight cities for which the hourly curves are shown in Fig. D-6. The RVR's obtained from the hourly data are, as expected, more conservative. In the regions of the country where the RVR is relatively low, there is very little difference in the rate obtained using either of the methods. Comparisons of the RVR's obtained by the hourly and daily average data are presented in the next part of this appendix.

c. The Shelter Effective Temperature/Adequacy Factor Criterion

In order to determine the RVR from the AF curves, the criterion of shelter effective temperature with respect to adequacy factor (SET/AF) must be established. As an example, ventilation rate requirements were determined using the SET/AF of 82°F/90% and compared with the rates for 85°F/95%. Required ventilation rates were obtained from both the hourly and daily average AF curves (Figs. D-6 and D-7); Table D-II summarizes the RVR's using these two SET/AF criteria. From these results (and also from observation of the AF curves of other cities) it is seen that the RVR obtained from hourly or average daily weather data does not differ greatly in areas where the RVR is small; however, significant differences are noted in areas where the RVR is larger. Of more importance

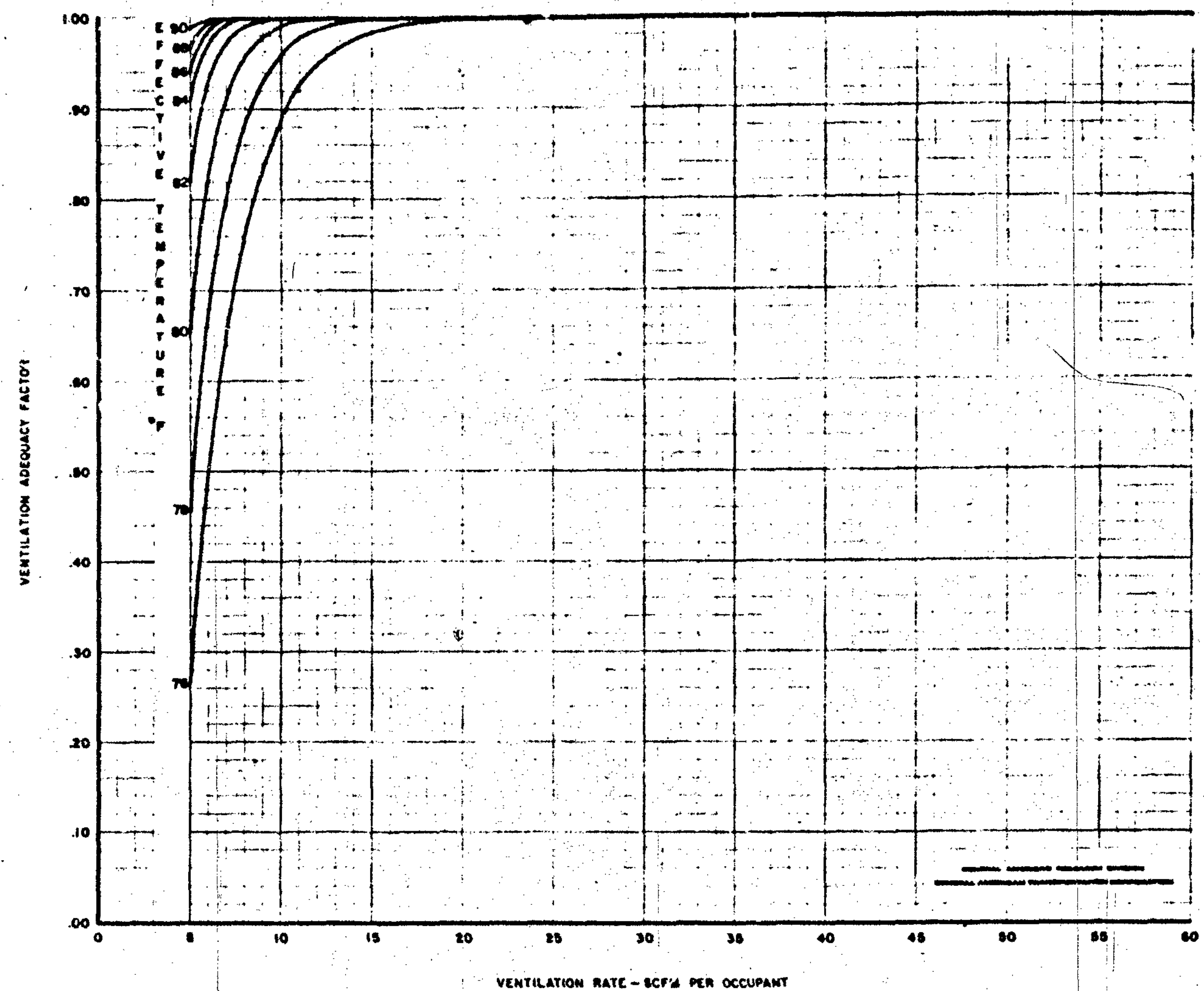

FIG. D-7 ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(a) Seattle, Washington

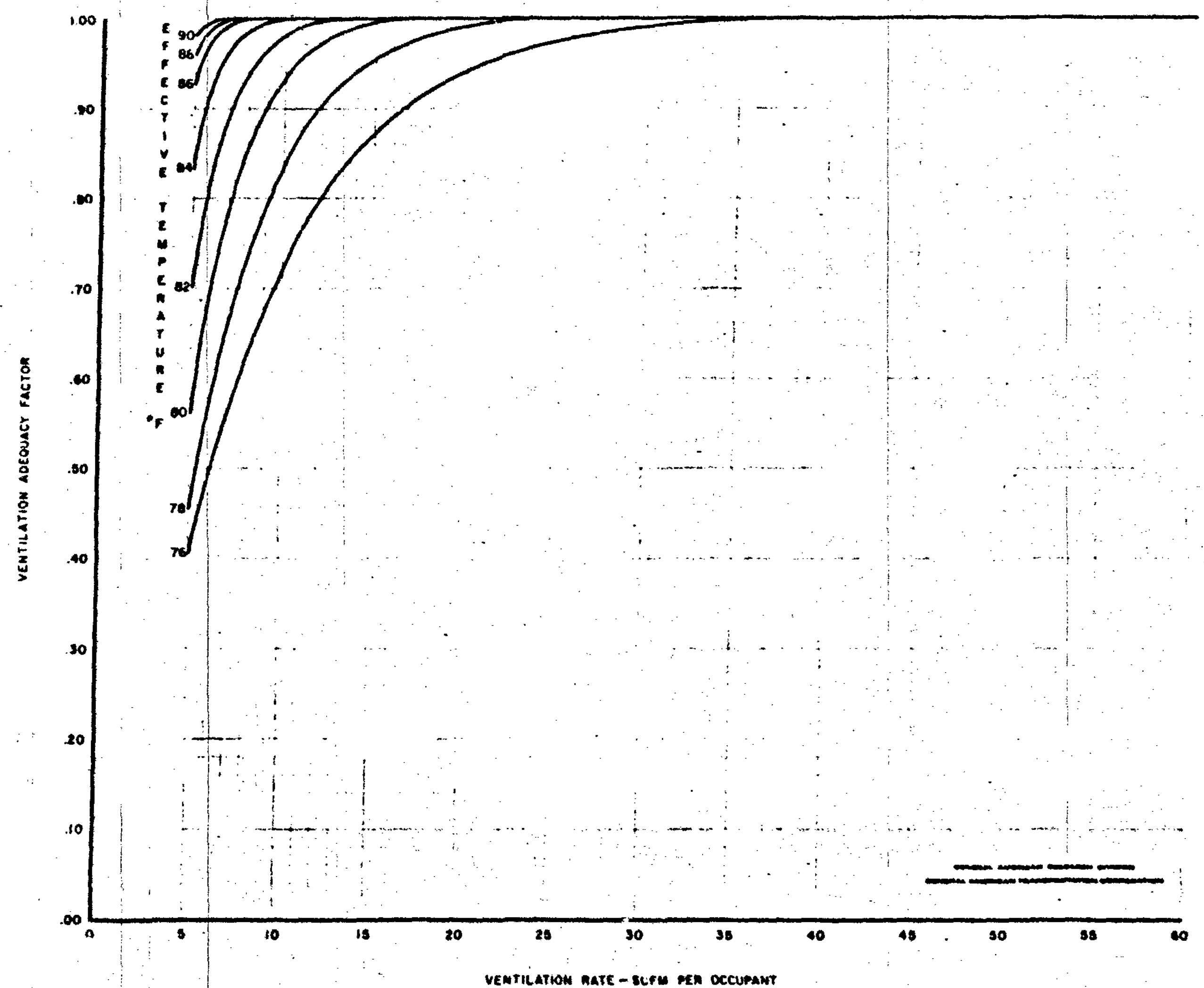

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(b) Denver, Colorado

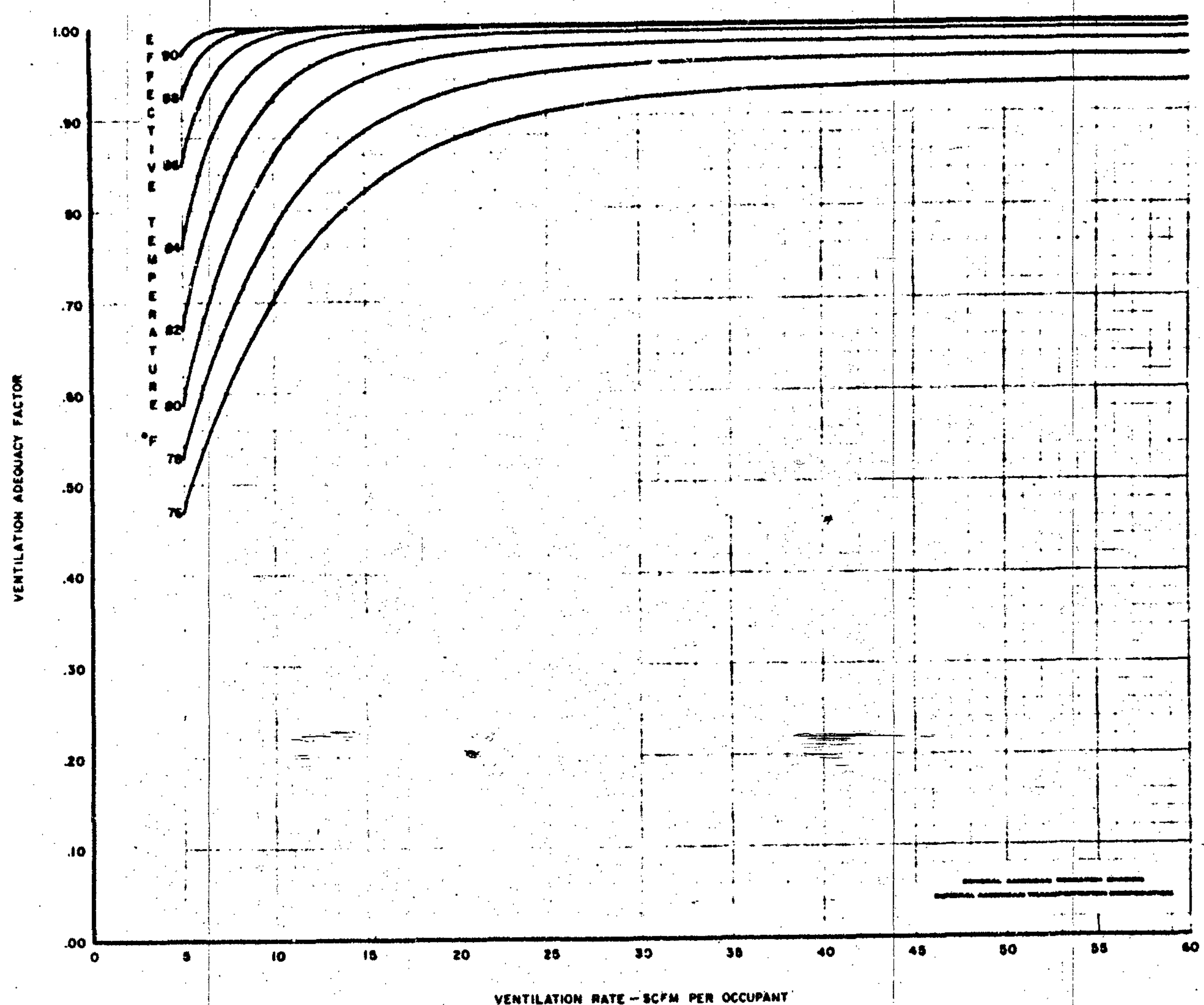

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(c) Minneapolis, Minnesota

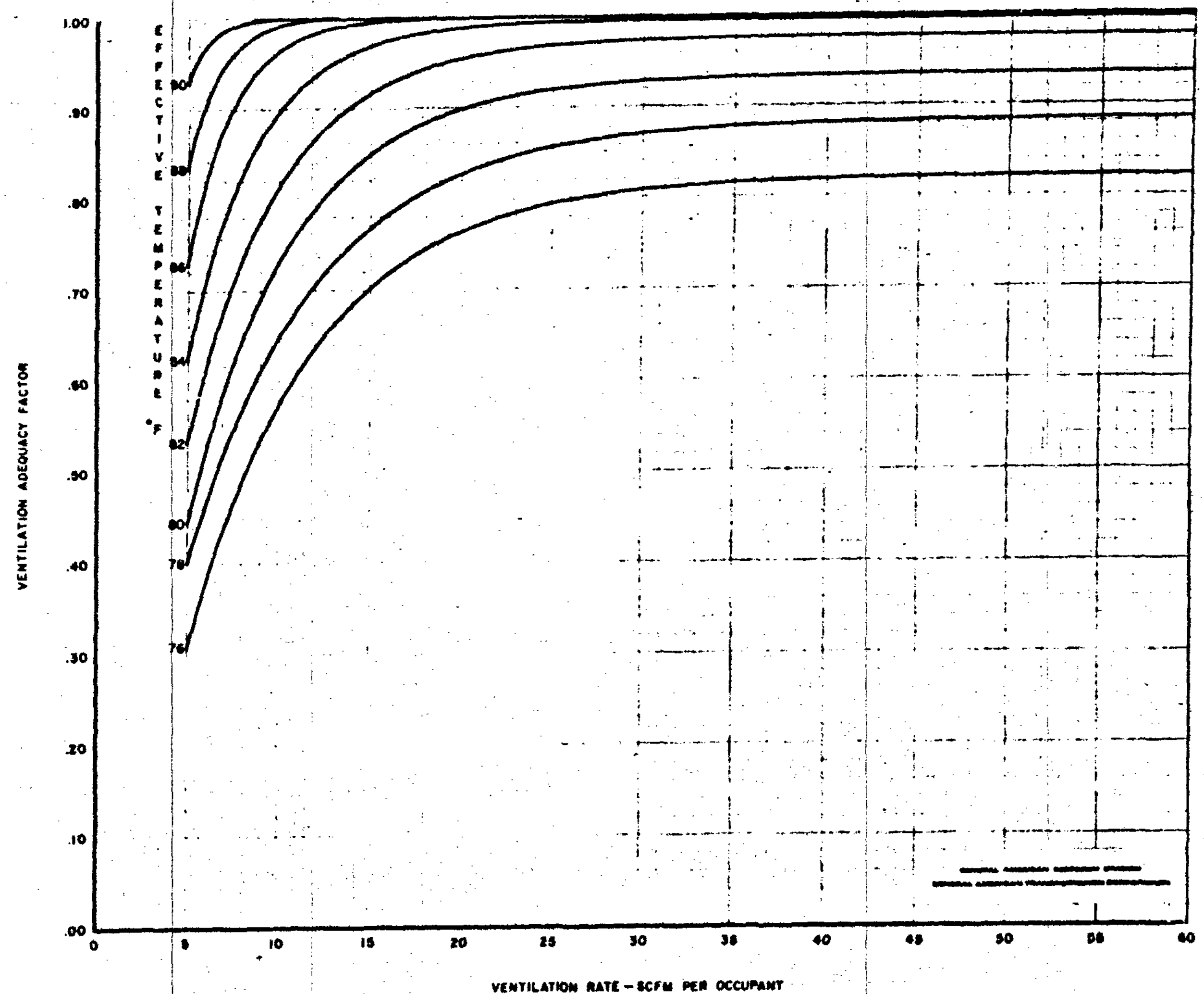

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(d) Washington, D.C.

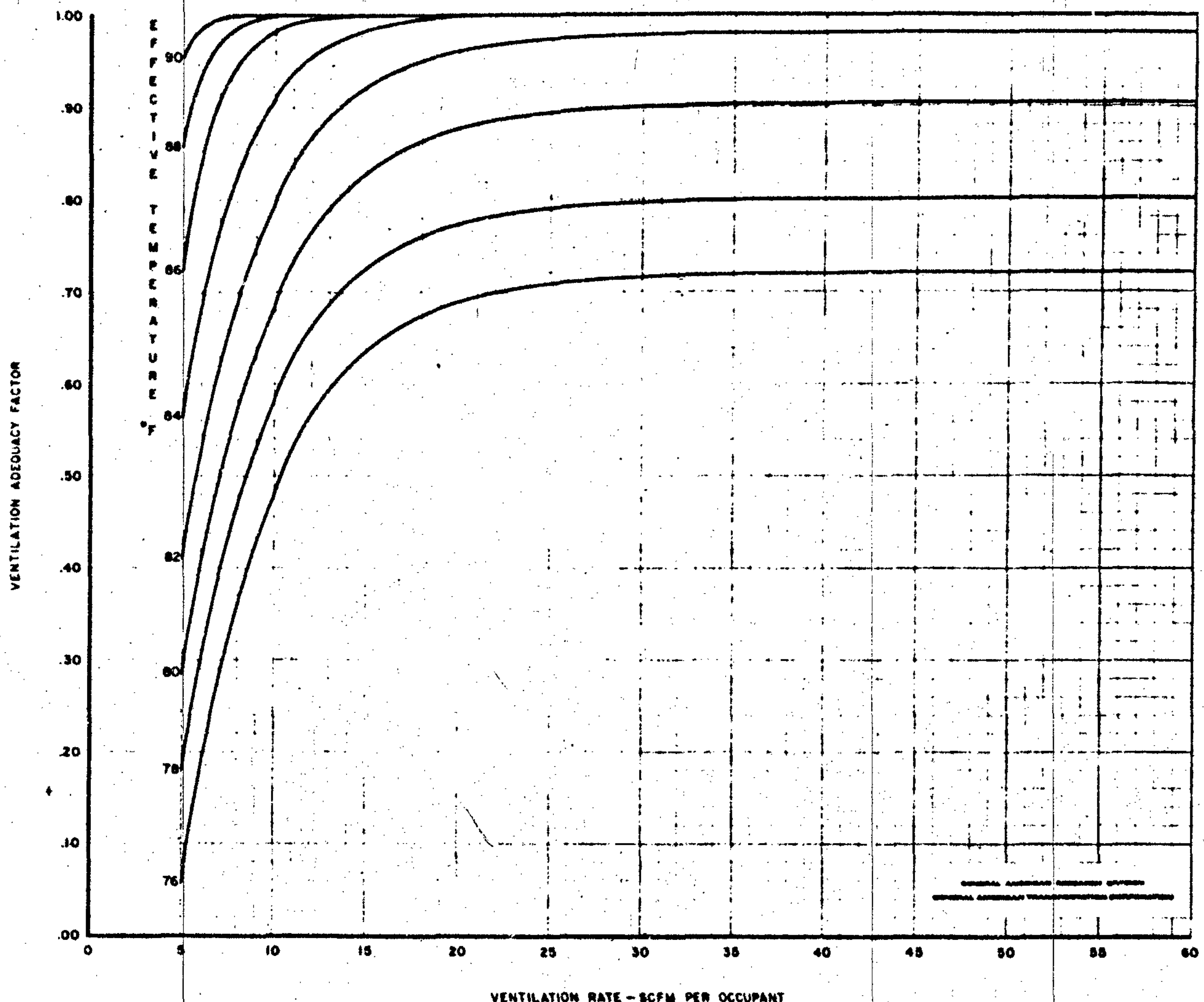

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(e) Tucson, Arizona

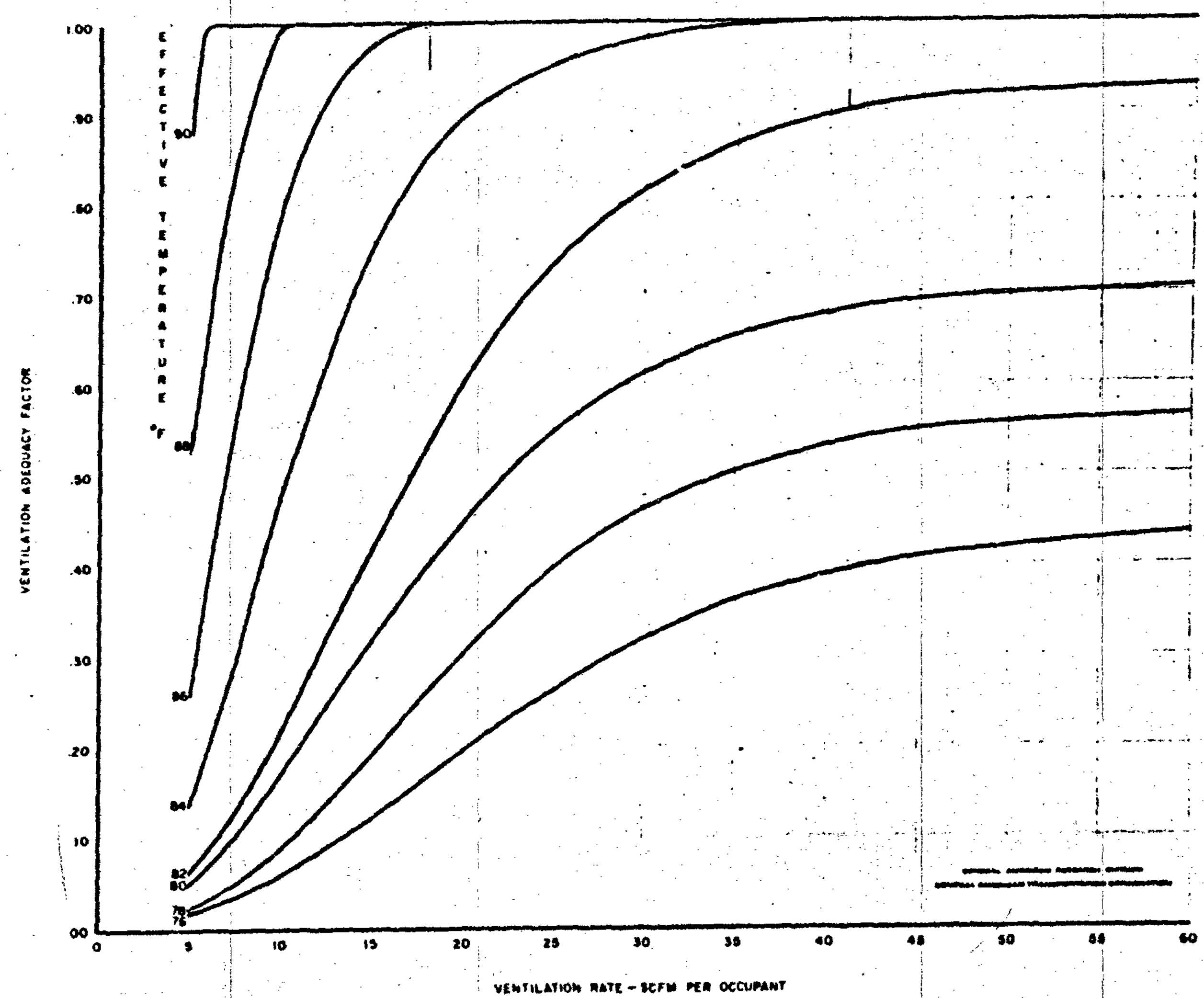

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(f) Miami, Florida

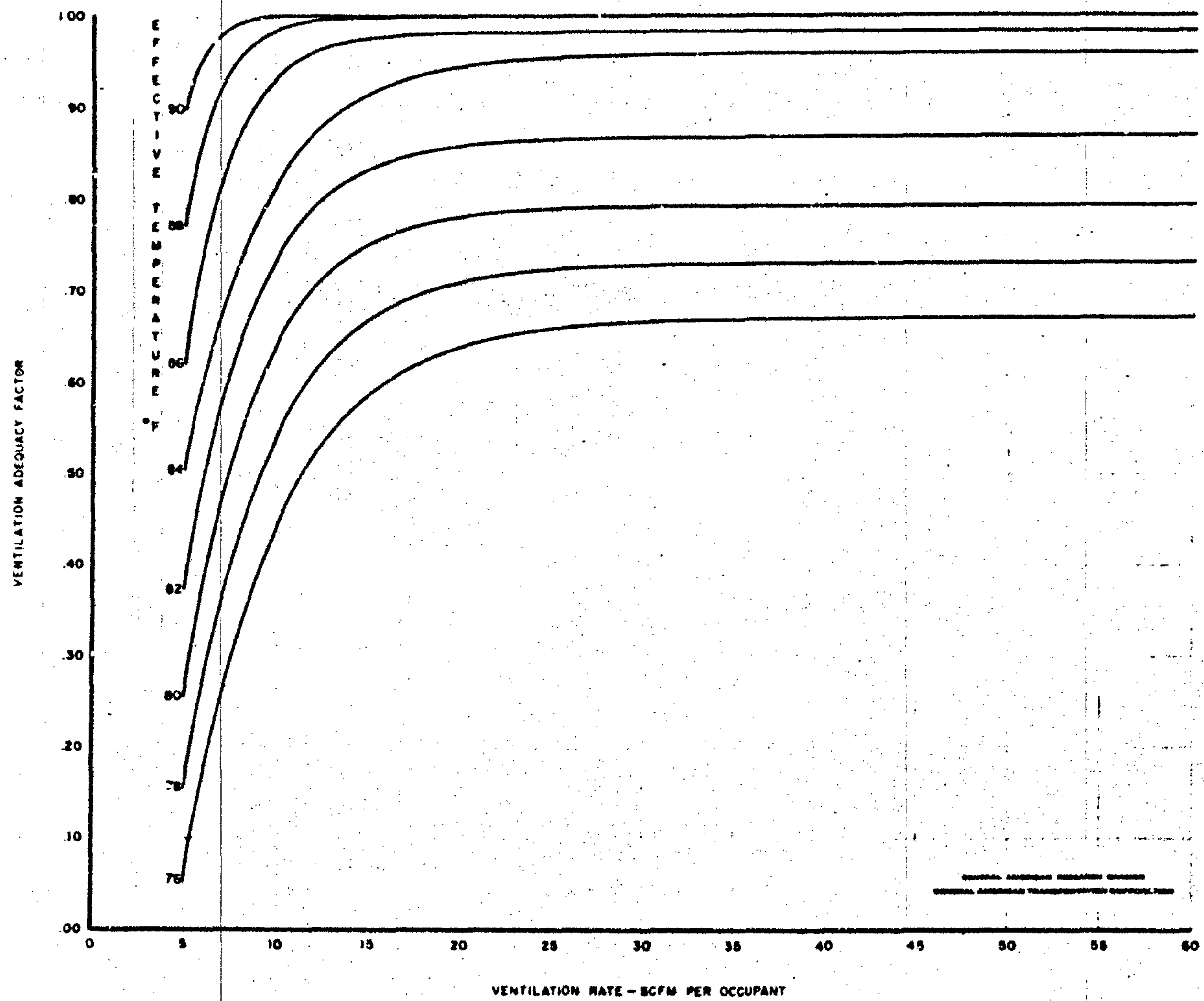

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(g) Phoenix, Arizona

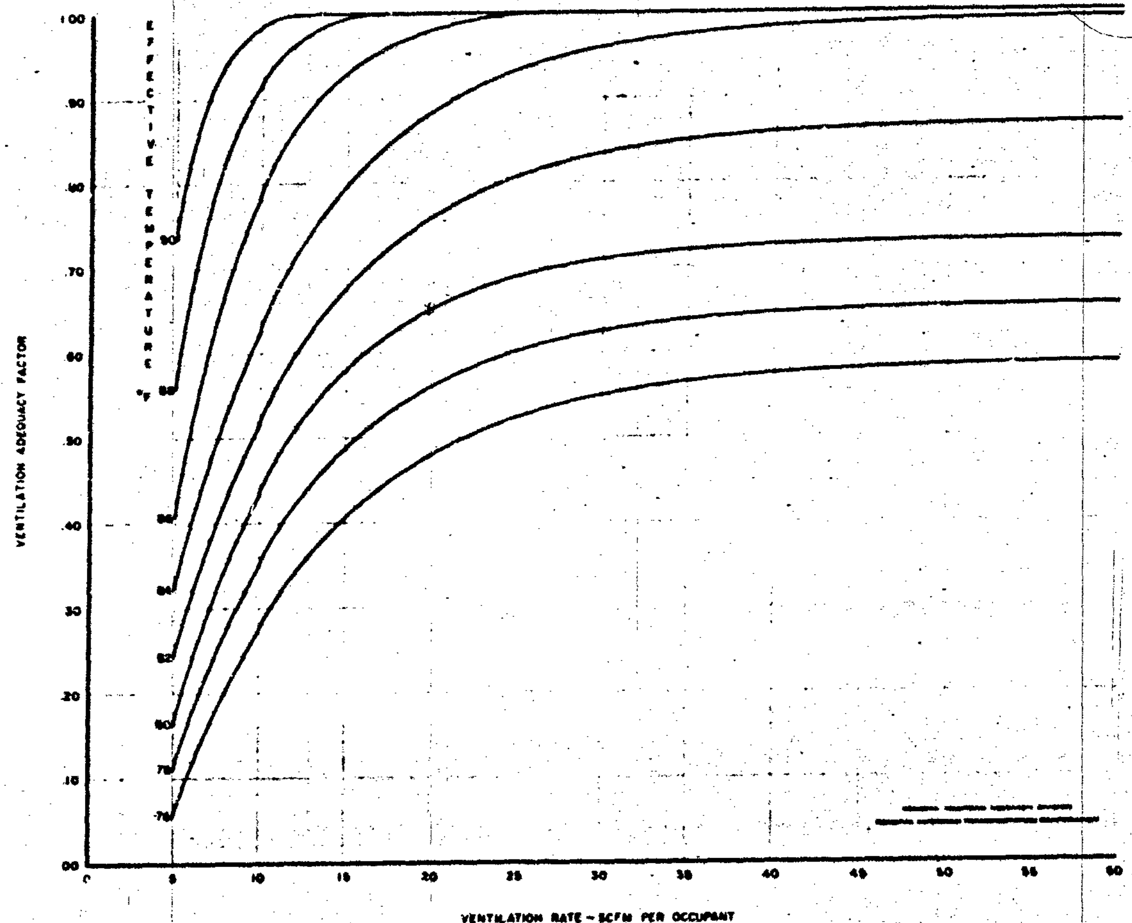

FIG. D-7 (Cont.) ADEQUACY FACTOR CURVES BASED ON DAILY DATA
(h) Houston, Texas

Table D-II

REQUIRED VENTILATION RATES FOR TWO SET/AF CRITERIA

	CFM Using the Criteria of 82°F ET at 90% AF		CFM Using the Criteria of 85°F ET at 95% AF	
	Hourly Data	Daily Average Data	Hourly Data	Daily Average Data
Seattle, Wash.	5.8	5.6	5.5	5.3
Denver, Colo.	7.4	7	6.1	5.9
Minneapolis, Minn.	9.2	9	8	7.8
Washington, D.C.	14.1	13.7	11.5	11
Tucson, Ariz.	16	13.5	11	10
Miami, Fla.	--	41	25	18
Phoenix, Ariz.	--	--	--	16
Houston, Tex.	--	--	25	22

is the difference in RVR with varying SET/AF criteria. Table D-II shows that the RVR from daily average data at a SET/AF of 82°/90% is in every case greater than the requirements using the hourly data at the 85°/95% criterion and illustrates the impact of the criteria. For a particular criterion, the RVR using the daily average data would be less than that obtained by using the hourly data. Shelter design condition cannot be maintained at Houston using ambient air at the 82°/90% SET/AF criterion, but a reasonable RVR (22 to 25 cfm) would be sufficient for a 85°/95% criterion.

The importance of a prudent choice of SET/AF criterion is therefore stressed. The determination of this criterion involves the study of physiological tolerances and the establishment of a probability factor of not exceeding the design temperature. Weather criteria and economic factors (equipment costs) will affect the choice of the probability factor.

The effective temperature as a measure of physiological response has been discussed in Appendix A. It was mentioned that a SET value of 85°F has been utilized only as a reference criterion to enable various tests results to be compared. More recently an adjusted ET criterion recommended for shelter environment has been presented in a report by

W. E. Strope.[28] An ET value of 82°F has been recommended based upon studies by physiologists and physicians of heat stress on humans.

The criterion using average temperature does not take into account the maximum and minimum temperatures of the daily cycle; however, results of several shelter tests have shown that the SET do not vary more than ±2°F from the average during any one day. The physiological effect of this small increase above the average may or may not be critical, depending upon the level of the average shelter temperature criteria. Because of the small daily amplitude of the SET and the close agreement between the predicted and test results using average values, it was concluded by GATX that the analysis of shelter environment be based on the daily average temperature. Such an analysis of test results would then be greatly simplified. The prediction of the ventilation rate can be accomplished by reference to the AF curves, since this becomes a steady-state problem. No method has yet been developed for establishing a consistent "average daily dry-bulb and wet-bulb temperature" criterion, which in essence is a single-point-criterion that can be used in a steady-state analysis. This difficulty was seen in the weather matrices (Part 1 of this section) where the RVR was defined by any of many combinations of DBT and WBT. This led to the adequacy factor method of determining the required shelter ventilation rate.

For establishing basic data such, as the AF curves, it is preferable to use hourly data, since such data are readily available for approximately 400 stations in the U.S. There is no reason to dispense with valuable information by averaging, especially since hourly data must be used in order to obtain the averages.

For the analyses of shelter test results, several reasons have already been presented to support the use of averaged shelter temperatures.

d. Application of the Adequacy Factor Curves

There has been much discussion on the shelter condition that may be expected during extreme weather conditions (during the period expressed by the inadequacy factor). While it might be generally accepted that the shelterees would be able to tolerate peak ET's for short periods of time,

the time depending upon the magnitude of the peak, no method has yet been developed for estimating the duration of the extreme condition.

Since the AF represents a probability factor that the shelter would be maintained at a certain ET, it would be logical to study the shelter condition that may be expected during extreme weather conditions, say at the 99% AF level. After the ventilation rate is obtained from the curve, a slight adjustment of this RVR may improve shelter conditions considerably in an extreme condition. This can be seen in the AF/RVR curves, that is, if the slope of the curve is steep in the region where the RVR value is read, a slight increase in ventilation rate would yield a substantial increase in the AF. On the other hand, in the region where the AF-CFM curve is flat, a decrease in ventilation rate will affect the shelter condition very little.

To illustrate these points, auxiliary curves shown in Fig. D-8 were drawn from data extracted from the curves of Fig. D-7. In Fig. D-8 two curves are drawn for each of six cities. These represent CFM lines obtained from the two SET/AF criteria of 82°F/90% and 85°F/95%, respectively. (From the observation of the curves on hand of 91 cities, the curves of the eight cities appear to be a representative cross section of the extreme conditions that prevail throughout the U.S.) The graphs were presented in this form to give some indication of the shelter conditions that may be expected under severe ambient conditions of 99% AF when ventilated at the rate determined by the above criteria.

From the observations of the curves, in general, the cities with a low RVR tend to have sharper increases in SET when severe climate is encountered (99% AF). However, a slight increase in the RVR is able to bring down the ETs to a more tolerable condition. This is evidenced in the graph for Seattle where at the RVR of 5.3 cfm (determined at 85°F/95% criteria), the SET can be expected to rise to 90°F at 99% AF. An increase of 1.3 cfm (to 6.6 cfm) would decrease the severe shelter ET to 85°F. (This increase is equivalent to a SET/AF criterion of 82°F/96%.) By observation of the other curves of cities with a relative low RVR, a similar increase in the ventilation rate can insure against an excessive high shelter ET at extreme climate conditions.

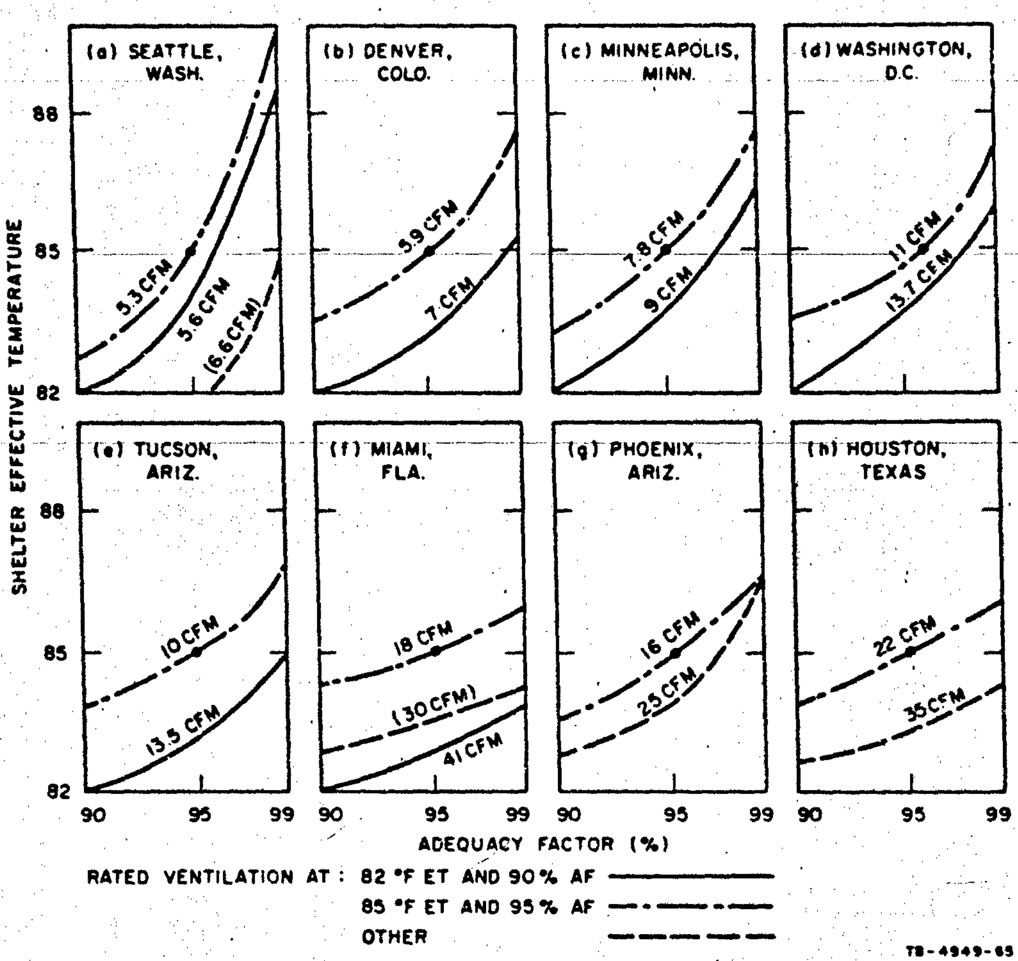

FIG. D-8 SHELTER EFFECTIVE TEMPERATURE AS A FUNCTION OF ADEQUACY FACTOR AT RATED VENTILATION

In the case of Miami, where the RVR is large, the increase in ETs is relatively small in extreme hot weather (at 99% AF). From the curve it can be seen that the RVR of 41 determined by the 82°/90% SET/AF criterion, would result in a rise only to 84°F at 99%. In this case even a decrease in ventilation rate to 30 would cause very little change in the shelter condition at 99% AF.

The graphs of Phoenix and Houston are shown in Fig. D-8(g) and D-8(h). Neither city can be ventilated by ambient air if the 82°F/90% criterion is used. For the city of Phoenix, it is seen from the curve that

no matter how much the ventilation rate is increased, the SET will be 86.7° at 99% AF. Above 25 cfm, the curve does not change. For Houston, the curve remains the same for ventilation rates above 35 cfm. It is recommended that direct adjustments, as stated earlier in the section, be made of the ventilation rates obtained from the adequacy curves. The adjustment may be a slight increase or a substantial decrease in ventilation rate, depending upon the slope of the AF curve, which in turn depends upon the geographical region. The adjusted ventilation rate should be used as the bases for developing the ventilation contour maps (Fig. D-9).

e. Discussions on Adequacy Factor

The adequacy factors corresponding to RVR for maintaining a given SET are derived from detailed weather information. This information is presented in a matrix tabulating the frequencies of occurrences of the coincident DBT and WBT.

In referring to the ten-year weather matrix shown in Fig. D-4, the frequencies of occurrence of the coincidence dry-bulb and wet-bulb temperatures are shown in hours. For the purpose of further discussion, let us use a SET/AF criterion of 82°F/90%. In applying this criterion to the matrix, the interpretation would be that, for all but 10% of the hours (8765 hours) during a ten-year period (87,650 hours) the design SET of 82°F or less will be maintained, for a given ventilation rate in an adiabatic shelter. Since the data were recorded for a relatively long period, the AF thus derived may be considered as for a typical year. It can then be re-stated that the 90% AF represents 876 hours out of a typical year during which it can be expected that the SET of 82°F can be expected to be exceeded. This exemplifies certain weaknesses in the above concept. First, it is highly probable that most of the 876 hours of inadequate ventilation rate will occur during the four or five summer months of each year. Secondly, the duration of each peak period during which a SET of 82°F is exceeded is not determinable. Therefore, the adequacy factor does not express a true probability that can be applied to any part of the year. For instance, it cannot be said that for any given day, the

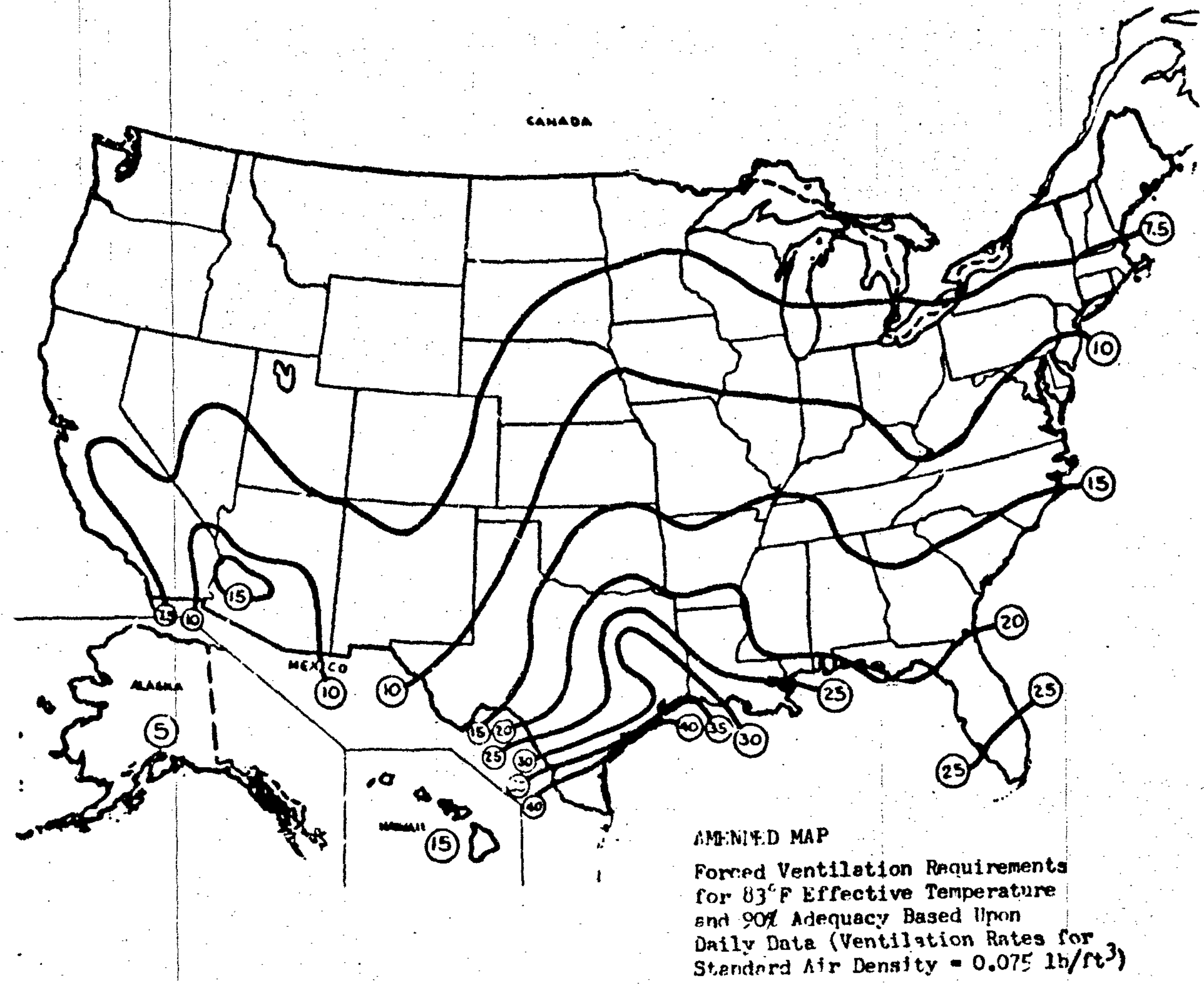

FIG. D-9 ISOVENTILATION CONTOURS FOR SET/AF CRITERION OF 83° F/90% BASED UPON DAILY DATA

design condition would not be exceeded for more than 10 percent of the day or 2.4 hours. If a reasonable assumption is made that the 876 hours (representing 10 percent inadequate hours of the year) would occur during the four summer months, then the 876 hours actually represent a 30 percent inadequacy for the four summer months. The assignment of an overall probability or annual AF takes into consideration the probability of shelter confinement occurring during the summer. However, since climate is grouped more or less according to season, the occurrences of inadequate days are not distributed evenly throughout the year. Therefore, in comparing AF's, that for the year would be greater than that for the summer months. For example, a 97% AF for the one year period would be equivalent to a 91% AF for the four summer months. Adequacy factor would be close to 100% for the remaining eight months.

The design data (DBT and WBT tabulated independently) presented in the ASHRAE Guide (Ref. 1, chap. 27) are based on temperature data of the months of June through September. While in many of the cities of the U.S. the higher DBT's and WBT's occur during the four summer months, there are some cities in which the period of high temperature may extend longer than four months. The period of time (portion of a year) to be used as a basis for determining summer AF should include the total consecutive months during which the higher DBT's and WBT's would be likely to occur. Adequacy factor curves based on say five summer months should cover all of the period of summer weather for nearly all cities of the U.S. In this way the grouped portion of the year during which the critical ventilation rate may be needed is established, whereas, the period during which the AF would not be meaningful (AF near to 100%) is not considered. This would most likely be an improved approach to establishing a more applicable SET/AF criterion.

3. Design Day Weather Cycle--Dynamic Criteria

The design day weather cycle is essentially a dynamic criterion, in contrast to the static criterion in which a single psychrometric point is used as a design parameter for a steady-state condition. The above cycle can be derived from the USWB hourly data for a particular locale,

using combinations such as the DBT and WBT data, dry-bulb and dewpoint temperatures, or other combinations.

In most of the shelter ventilation tests conducted, the air supply was conditioned to conform to the particular design day temperature cycle pertinent to the shelter location. (Comments on the use of conditioned air are made in Appendix B.) Still more important, the dynamic criteria in the form of the design day weather cycle must be established in order to provide weather input data for the transient analysis.

NBS in their paper,[20] discusses briefly the dynamic or diurnal criteria to a limited extent only since this involves the further study of physiological tolerance toward shelter climate when a design effective temperature is exceeded for certain number of hours during the day as a result of the outdoor diurnal swing.

a. Design Day Cycle as Defined by GATX

General American Transportation Corp., in their shelter ventilation experiments, used a design day developed in the following manner:

(1) DBT's (hourly) were compiled from the USWB data for 3 summer months of several years.

(2) The DBT's for each specific hour of the day were averaged using the data of several years. This constituted the average DBT cycle.

(3) From the hourly temperature data (1) a single value of maximum DBT that is equalled or exceeded for 5 percent of the hours in the three summer months was found.

(4) The maximum temperature of the average cycle is elevated to the maximum 5 percent temperature of (3) above. Using this as a peak, and increasing the DBT of the average cycle for all other hours, by the same difference, a 5 percent dry-bulb cycle is obtained.

(5) From the Weather Bureau wet-bulb data, a single value 5 percent WBT is obtained. This is used with the single value 5 percent DBT in (3) above to determine a single design dewpoint temperature. The use of a constant dewpoint is assumed since from weather data, the variation of dewpoint for any one day was found to be small.

(6) The single value of dewpoint thus obtained is assumed to occur with the 5 percent DBT cycle to define the design day weather cycle. The design day ET is developed from the DBT cycle and the dewpoint.

It would appear that the "5 percent dry-bulb cycle" could be obtained on a more rational basis than that of elevating the average DBT cycle by a uniform amount. It is implicit in this technique that the amplitude of the 5 percent DBT cycle is the same as the amplitude of the average DBT cycle. Whether they are always the same or not is not really known. It is apparent that the above method of design day cycle was developed primarily for use in shelter tests, since ventilating air conforming to the above weather cycle can be easily generated by the OCD test vehicle by cycling the DBT as a function of the time of day and by maintaining a constant dewpoint.

b. University of Florida Design Day Cycle--
Enthalpy and Effective Temperature Criteria

In the final report of the University of Florida entitled "Simulated Occupancy Shelter Tests" the possible development of a design ambient diurnal cycle based upon either the enthalpy or effective temperature criteria was discussed. The high design day generated from the data compiled for Lakeside, California[23] was presented as an example in the form of a DBT cycle with the accompanying WBT cycle. The values used to generate these curves represented temperature variations that would not be exceeded for more than 1 percent of the time during any summer season. It was not mentioned whether the WBT's and DBT's were coincident or independent. The enthalpy criterion can be established by using the 1 percent design WBT cycle since the measure of WBT represents a nearly true indication of the enthalpy magnitude. It was not clear how the corresponding DBT cycle was generated. For the effective temperature criterion, the 1 percent DBT cycle was probably used, but the method by which the curve was generated of the corresponding WBT cycle is not clear. It is obvious that the high WBT cycle was not used in the latter case, since this would produce a similar WBT curve as that generated for the enthalpy criteria.

It was commented in the Lakeside report that the use of more than one design day may be necessary since in many cases the period of ambient climate conditions in a given locality which are most severe with respect to enthalpy are not always coincident with the periods of highest ET's.

The various criteria can be seen from Fig. D-10 in which the effective temperature lines are superimposed on the chart of Fig. D-3. If the points along an isoventilation line are observed, it is seen that the ventilation rate required of the inlet air at a certain ET and enthalpy state can be the same as that of the air at a lower ET and higher enthalpy, or vice versa. It is also seen that different ventilation rates are required for inlet air at various psychrometric conditions but at the same ET, or same enthalpy. Thus it is difficult to establish a criteria based either on enthalpy or effective temperature condition of the ventilating air.

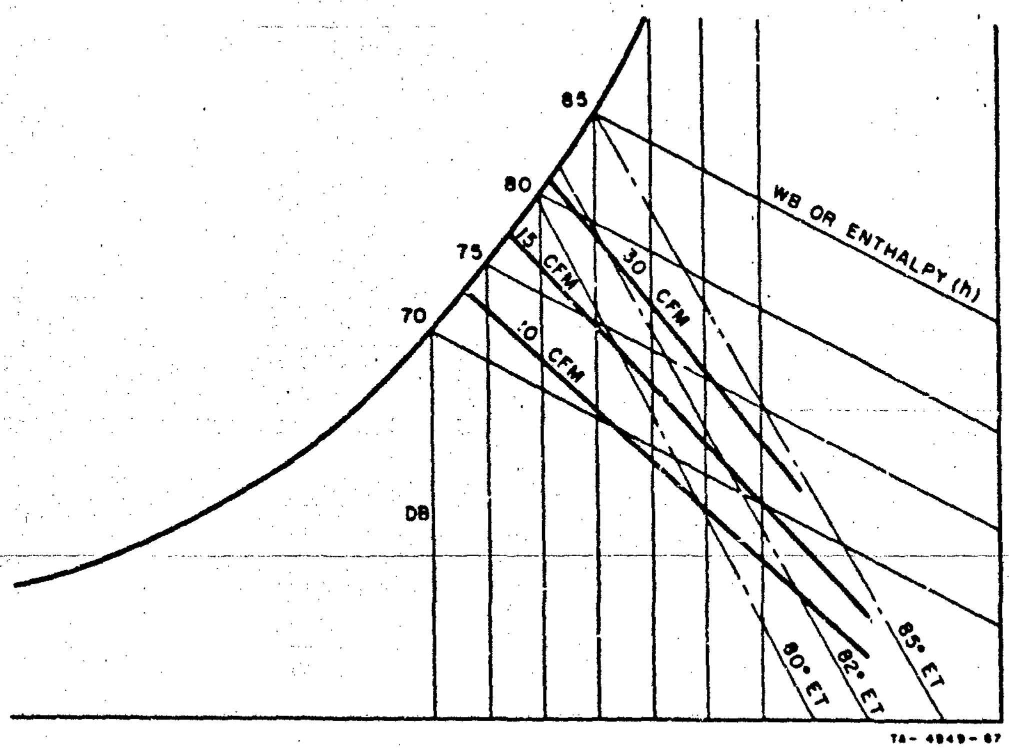

FIG. D-10 COMPARISON OF DESIGN DATA CRITERIA

c. Design Day as Developed by IIT Research Institute

IIT Research Institute conducted a series of experiments on a shelter buried under uniform sand, and developed a design day cycle using summer weather records of the warmer population centers in the U.S. Typical data on hot and humid summer conditions in four cities (Washington, D.C., Dallas, New Orleans, and Atlanta), were selected on basis of high ambient ET's extending with relatively small variations for several days. Hence, for a continuous 14-day period, these conditions may be considered as extreme.

It was observed from the data that the highest and lowest DBT's are offset from one another by about 12 hours, while dewpoint temperature varies relatively little throughout the day. On the basis of this data, the temperature humidity cycle that was selected by IIT Research Institute for the shelter ventilation air took the form of a sinusoidal variation of the DBT, together with a constant dewpoint temperature.

A sine function diurnal cycle would provide an equation to work from, and only the value of the amplitude and the maximu value of the cycle need be known. Whether the sine cycle or a cycle made up of hourly discrete values is more applicable for use as input data would depend on its end application. For a computer input, a set of discrete values may be more useful, whereas analytical solutions on paper would find the sine function more appropriate. The sine temperature cycle developed by IIT Research Institute was based on the data of four cities and represented a typical summer day. This was used as input for their shelter tests. Such design day weather cycles if used, would be needed for each individual city.

d. Discussion

It is necessary to study the various methods of developing the design day weather cycle in order to establish a dynamic criterion that may be used as input information for transient analysis. Such criteria must be derived from a rational use of available weather data.

In the author's opinion, an example of a more realistic approach to the development of a design cycle is one in which the hourly points in the cycle are established by using the 5 percent or 10 percent WBT's for each hour in combination with a DBT cycle, in which hourly point is made up of the DBT that occur most frequently with the corresponding 5 percent (or 10 percent) WBT. This criterion is expanded from the NBS discussion on the single-point criterion using the 5% WBT with the most frequent occurring DBT (Part 1 above; also Ref. 20). This approach really represents an effort to retain partially the coincidence of DBT and WBT.

Another reason for suggesting this method was the fact that the SET is more sensitive to a change in the ventilating air WBT at a constant DBT than vice versa in a hot environment (SET > 76.4^{o} ET, see Fig. D-1).

The transient analysis of the shelter climate involves the input of the dynamic weather condition over several consecutive days. By establishing a single design day cycle (for each geographical location), there is no alternative but to use the common cycle as weather data input for each of the successive days. Since this process assumes that the high design cycle occurs on consecutive days, the ventilation rate obtained from the analysis would tend to be conservative. In Part 3 of Appendix F, additional discussions are presented on the use of the design day.

Appendix E

EXTENT OF APPLICABILITY OF WEATHER BUREAU RECORDS

Ventilation and cooling of fallout shelters during occupancy would generally be accomplished through direct utilization of ambient air. Various shelter ventilation tests and studies of weather records have shown that the vast majority of the shelters in the U.S. can be ventilated directly with ambient air, assuming that the shelter environment is to be maintained at a relatively high effective temperature as compared to comfort conditions.

In order to establish the design psychrometric condition for the ventilating air available to shelters, the nearby USWB records and/or other weather service records would be employed. Ventilation adequacy factors with respect to particular ET values can be computed from these records.

It is apparent that the knowledge of the psychrometric condition of the shelter proximate air to a given shelter is of prime importance, since this condition is the major influencing parameter in the computation of shelter ventilation requirements, regardless of the methods used for computation (adiabatic, nonadiabatic, transient, steady-state). Since a reliable prediction of shelter ventilation requirement depends in turn upon the reliability of available weather data, we have devoted some efforts to studying the validity of weather records as they may be applied in determining weather design criteria at the specific shelter location. Wang,[29] a consulting meteorologist, comments as follows:

> "There are approximately 400 official weather stations in the U.S. providing coincident hourly records for temperature and humidity records for periods varying from 5 to 60 years. For the derivation of the adequacy factor, the nearby USWB records are used. However, due to the difference in micro-environments, the climate of the weather station and exterior

climate of a shelter may differ from one another appreciably. These differences, which may be thought of as extremely localized weather conditions, cause significant bias in the computation of the ventilation adequacy factor. Many of the weather stations are located at some distance from the actual locations of identified shelters, thereby contributing to the discrepancies; also, variation in the exposure of the weather station to its immediate surroundings contributes greatly to the deviation. As an example, in the weather stations located in airports, the humidity and temperature recordings may be taken either adjacent to concrete buildings or over moist grass or over bare soil of different types. A weather station may be located near a building, a forest or a body of water; whereas, the shelter surroundings may be entirely different. The differences in temperature between the weather stations and the fallout shelters may range from a few degrees to as much as 30°F, and the relative humidity may differ from 5 to 50%. In addition, some of the weather stations have been moved several times from place to place, but within a limited area; and also, the system of observation and instrumentation has been altered from time to time. As a result, the reliability of the historical records of some stations are questionable."

Wang's report discusses in some detail the various sources of weather data in the U.S. and climatic data as it may be affected by such factors as instrument error and geographical influences. Brief discussions are presented on methods of modifying climatic data for more realistic application to localized conditions. Wang has recommended that climatic data of a localized nature (at several of the shelter sites) be recorded for a short period of from two to five years, adopting the volunteer observation system used by the USWB. The results of such measurements could be used to establish statistical correlation between the data

of the shelter site station and that of the USWB. The short-term climatic data could then be extrapolated to a long-term, Weather Bureau-type record, more representative of the design conditions of the specific shelter site.

While it is generally agreed that a difference may exist between actual climatic conditions at the shelter site and at the official USWB station, it would be a tremendous task to make climatic measurements of each shelter area and then correlate these sets of data to the official records. Grouping or classifying several local shelters might decrease the number of measurements, but a large quantity of work would remain. A critical conditions would exist, however, if the weather conditions of the shelter vicinity were consistently more severe than that recorded by USWB data for the area.

The initial ventilation requirement information in cfm/occupant prepared on a nationwide basis by GATX in the form of isoventilation lines can be expected to contain discrepancies, since these isoventilation "contours" are obtained from interpolation of USWB data of the principal cities.

Since the parameter of climatic data is so dominant in the determination of shelter ventilation requirements, correlation weather studies of key population centers are recommended. (In an adiabatic shelter, only the climatic information is necessary in addition to the data on the number of occupants.) The studies can initially be conducted on a small scale with localized climatic records kept of urban shelter areas. It would be absolutely necessary to standarize the instrumentation for all areas. Should the preliminary tests prove that discrepancies exist between the USWB data and the shelter data, and should those discrepancies greatly influence ventilation requirements, it would be necessary to plan a more intensive program for extended weather tests. Applicable data that would be eventually developed from these studies would be extremely beneficial to other fields, such as air conditioning and agriculture.

As a sample comparison, the ambient temperature records from a few of the shelter tests were selected at random and compared with the USWB records of that area for the corresponding test days. The comparative temperature curves are shown in Figs. E-1 through E-6.

The curves all represent weather cycle of a single day. While the discrepancies between the hourly U.S.W.B. recordings and the "on site" readings at some points are observed to be as high as 10^0, it is difficult to conclude from this brief comparison what the discrepancies would be over the long term average data. Some of the discrepancies appear to be simply from the phase shift of the curve which would be expected since such hourly data would not be recorded at exactly the same time by different parties. The occasional "spikes" on the curve are most likely due to temporary instrument disconnection. It would appear that occurrences such as that mentioned in Dr. Wang's statement "difference in temperature may range as much as 30^0F" would be quite rare.

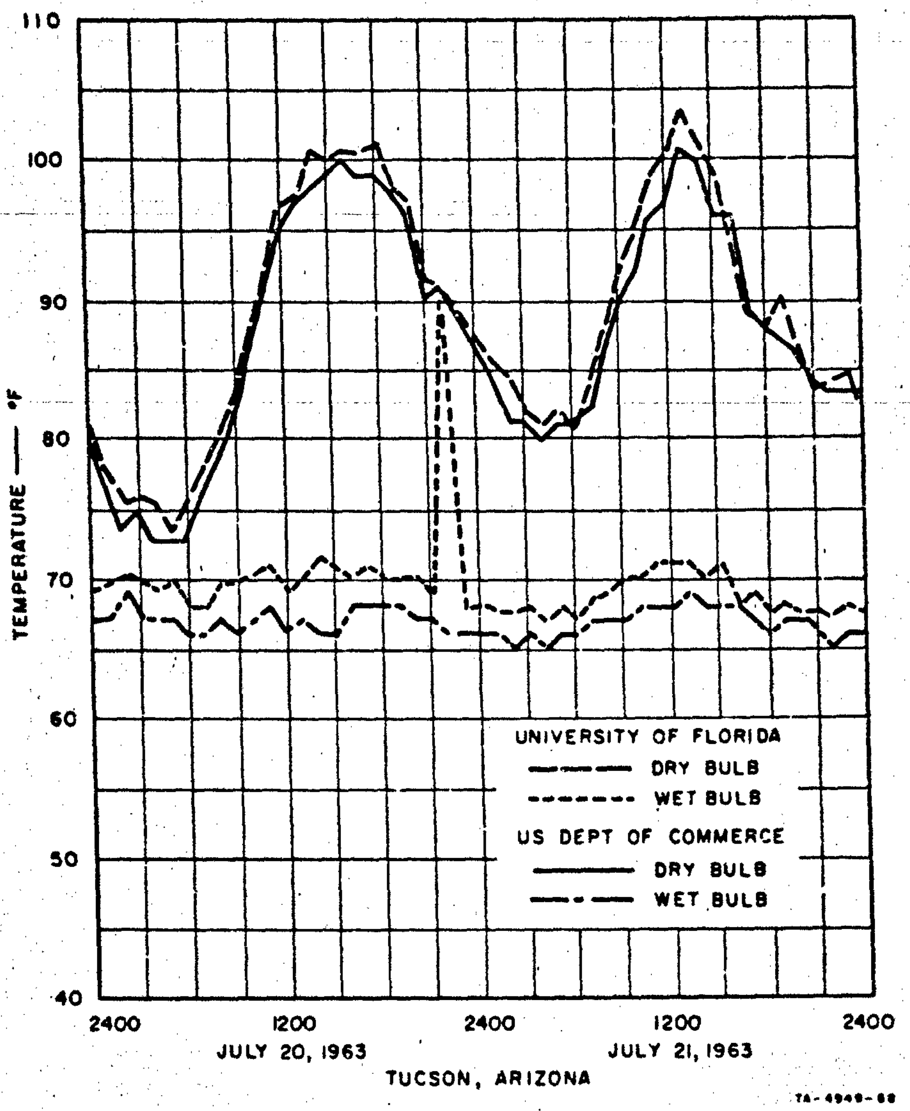

FIG. E-1 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, TUCSON, ARIZONA, 20–21 JULY 1963

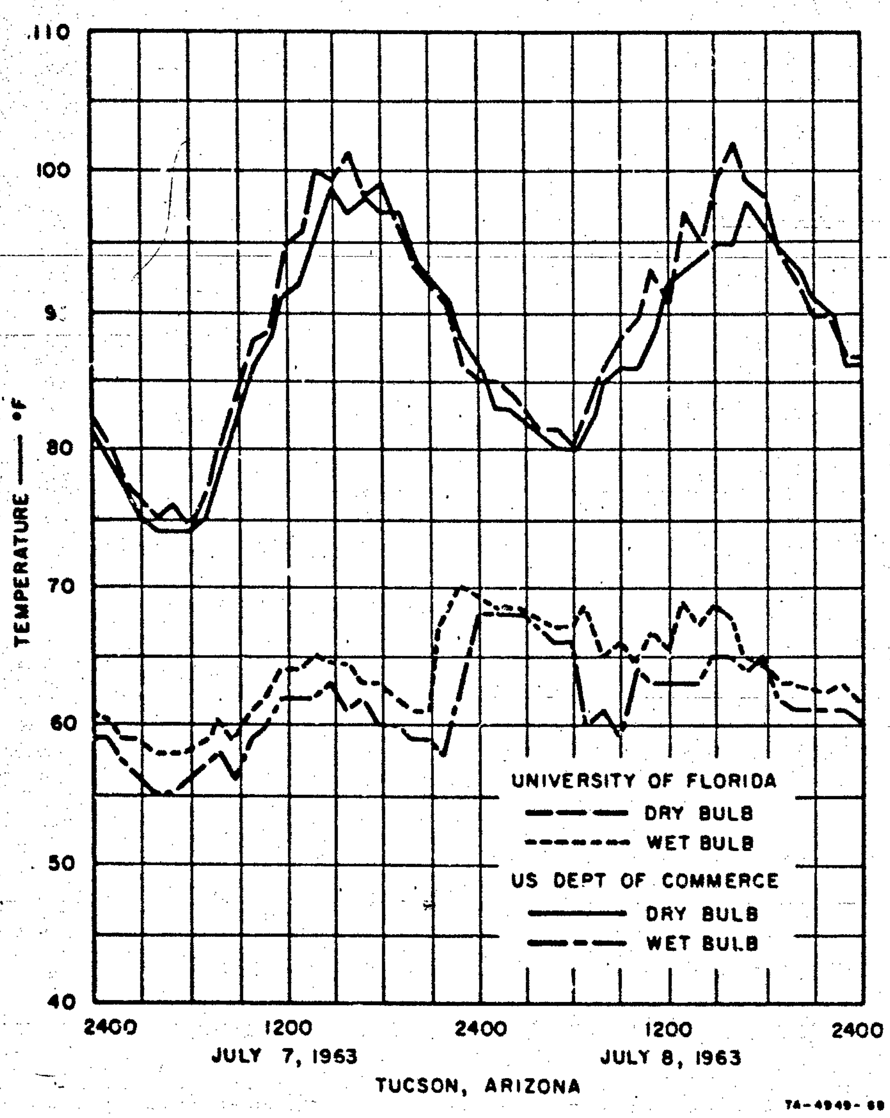

FIG. E-2 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, TUCSON, ARIZONA, 7-8 JULY 1963

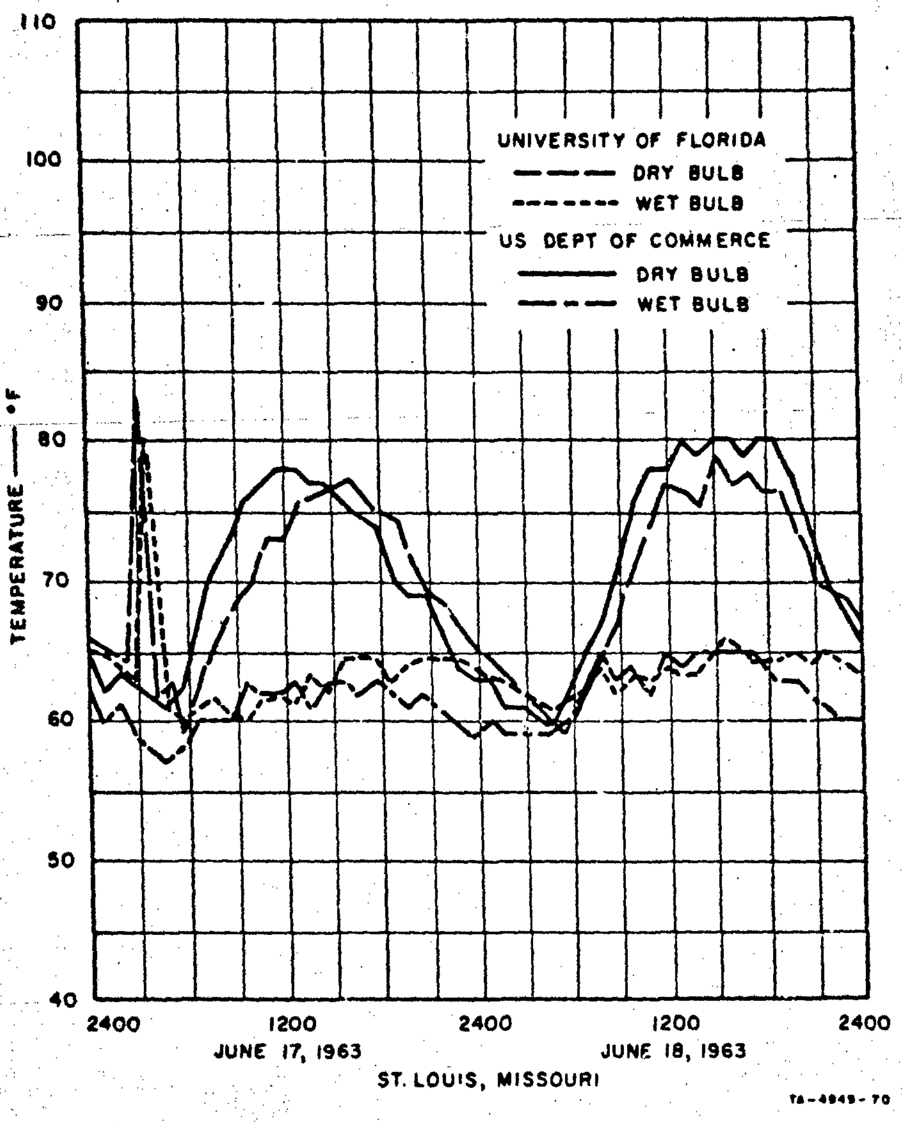

FIG. E-3 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, ST. LOUIS, MISSOURI, 17–18 JUNE 1963

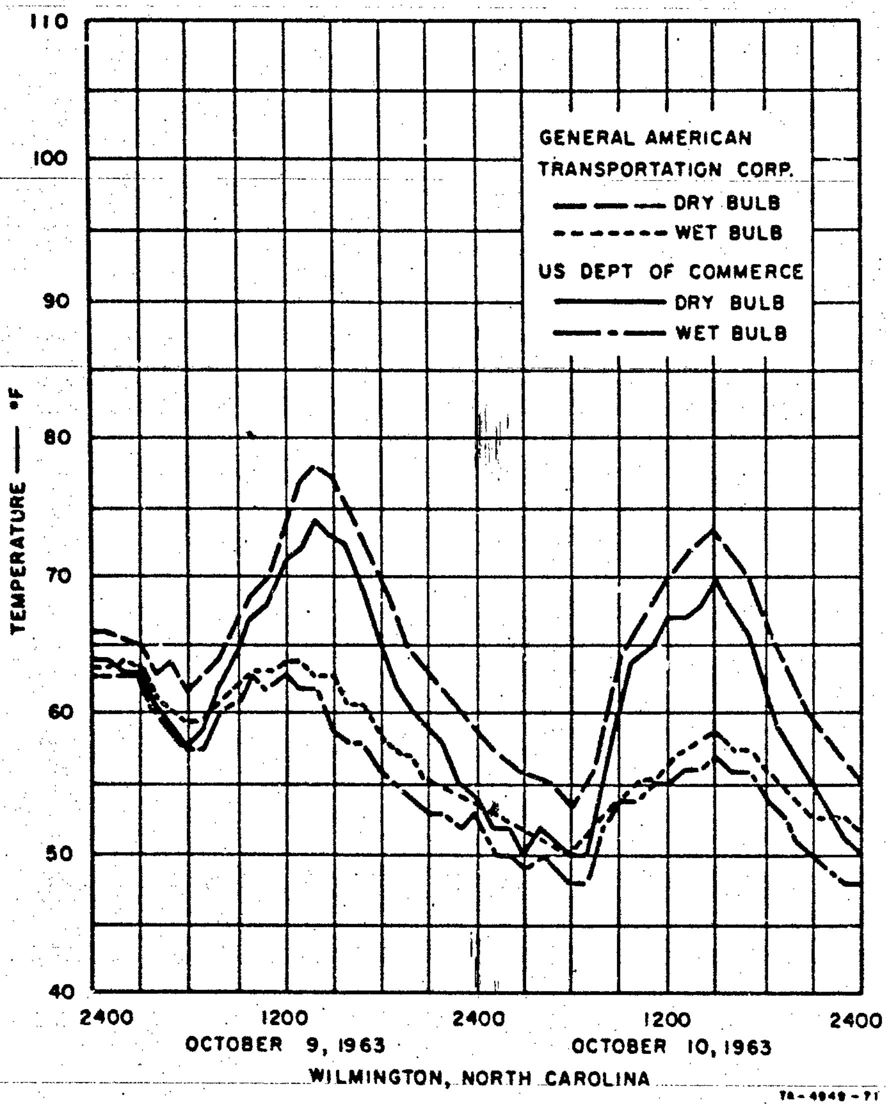

FIG. E-4 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, WILMINGTON, NORTH CAROLINA, 9–10 OCTOBER 1963

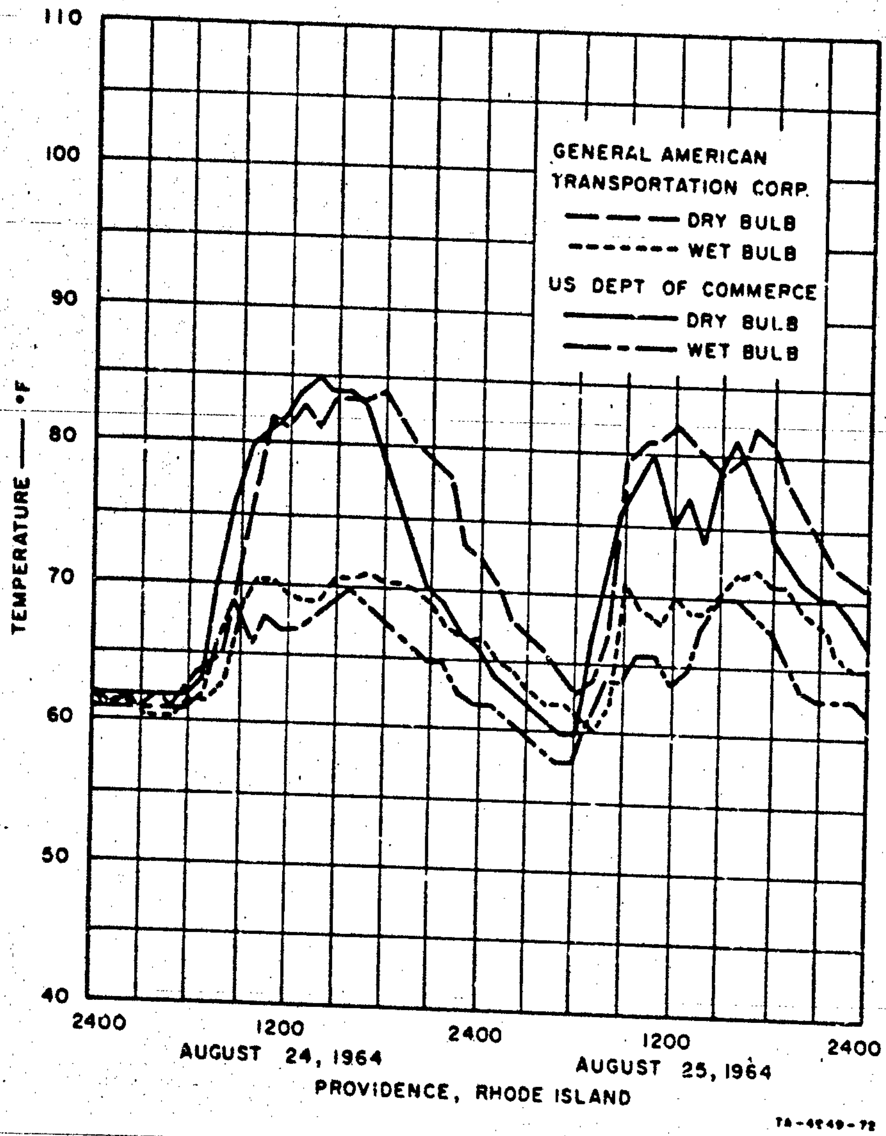

FIG. E-5 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, PROVIDENCE, RHODE ISLAND, 24–25 AUGUST 1964

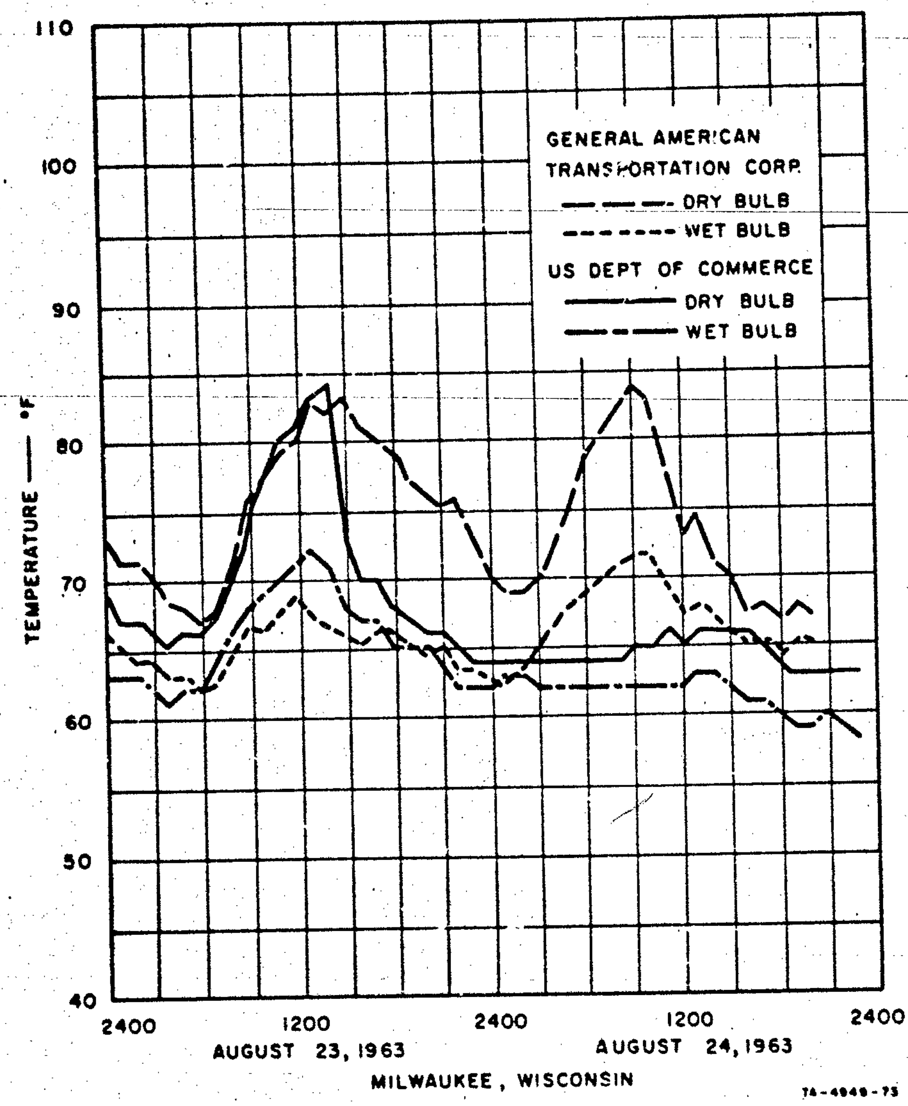

FIG. E-6 COMPARISON OF SHELTER AMBIENT TEMPERATURE AND USWB RECORDS, MILWAUKEE, WISCONSIN, 23–24 AUGUST 1963

Appendix F

DISCUSSION OF SHELTER VENTILATION REQUIREMENTS OBTAINED BY USE OF VARIOUS METHODS

Among the large number of reports evaluated, several methods of approach to the shelter ventilation problem have been outlined. Among these are the adiabatic method, steady-state heat transmission analysis, transient heat transmission analysis, one-dimensional heat transfer model, three-dimensional heat transfer model, and others. As a result of our study, we envisage three different levels of approach to the shelter ventilation problem: the adiabatic wall model, corrections to be made to the basic adiabatic model, and detailed analysis by use of the computer program. The shelter test program at Providence, Rhode Island is also included in this section as it presents a summary of comparisons of the experimental and analytical results.

1. Basic Ventilation Rate Determined from the Adiabatic Shelter Model

The ventilation requirement obtained from the SET/AF curves represents the unit rate (per occupant) based on an adiabatic shelter and assuming a load of 400 Btu/h/occ. Although the ventilation rate may not be directly applicable to many of the shelters, it establishes a base value to which various correction factors may be applied, depending upon the degree to which a particular shelter approaches the adiabatic shelter. The authors are in complete agreement with the several contractors that the adiabatic model should be adopted as a basis for establishing shelter ventilation requirements. The reasons are many:

(1) It is kept simple by the elimination of certain less influential parameters.

(2) It decreases the risk of inadequate ventilation (more complex methods may purport to be more accurate but leave little margin of safety).

(3) It is a close approximation for determining ventilation rates for above-ground shelters located in warmer regions and for large under-ground shelters (low ratio of wall-to-floor area). As the confinement period is

extended to the two weeks, the below-ground shelter condition will also tend to approach the adiabatic condition.

(4) The basic rate can readily be modified by adding the influences of other parameters (see Part 2, below).

The great value of the adiabatic method is its simplicity. It disregards all special features of each individual shelter and the only information required is the number of occupants and the geographical location. Any improvement over the adiabatic method must be capable of a more accurate prediction of the ventilation rate combined with the requirement that the cost of obtaining information resulting in increased accuracy is offset by the cost savings due to a decrease in the capacity of the ventilation system.

2. Corrections to Adiabatic Results for Boundary Heat Loss

Some adjustments may be necessary to whatever basic adiabatic ventilation rate is determined. The following lists some suggested adjustments:

(1) Adjustment by inspection of the adequacy factor curve--This correction, discussed in Part 2-d of Appendix D involves a small compensation to prevent excessive shelter effective temperatures at extreme ambient condition. A small increase in ventilation rate may prevent this in some cities; in contrast, for cities with a large required ventilation rate, a substantial decrease in the rate will not greatly worsen the shelter condition.

(2) Adjustment for boundary wall losses--The problem of determining the amount of heat that would be removed through the boundary walls has not been completely solved. Considerable study has been devoted to the determination of the magnitude of boundary losses. While it would be impractical to make detailed studies of heat transfer properties of each shelter, it may be possible to establish a conservative value of boundary loss expressed as a percentage of total shelter load, depending upon the geographical location and type of structure. Since the net shelter heat load that must be removed by the ventilating air would be reduced by this percentage, the required ventilation rate obtained from the adiabatic shelter adequacy factor curve can be reduced by a proportional amount.

In Phase 1 of the National Fallout Shelter Survey, approximately 375,000 shelters were surveyed by subcontractors, who obtained information including the type of construction. A review of this survey might indicate the possibility of classifying shelters into relatively small groups and assigning the value of the percentage of boundary heat loss for various type shelters. This screening should be kept as simple as possible and heat loss values kept on the conservative side so as not to reduce the ventilation rate excessively. It is recommended that shelters which would not need values adjusted be identified, that is, treat them as adiabatic shelters so that attention can be directed only toward those cases requiring correction. In cases where the proportion of boundary loss is relatively small, a substantial error in the transfer coefficient would have little effect on the change in the required ventilation rate. As an example, in a parametric study by Dr. Drucker (Part 4 of Appendix C), it was found that the shelter effective temperature varied no more than $1^{o}F$ when the earth conductivity coefficient was varied from 0.3 to 1.15 Btu/hr-ft-^{o}F. By applying a correction factor based on the percentage of boundary loss, a determination of the absolute value of the heat transfer coefficient can probably be avoided. (Even many of the coefficients found in engineering tables are presented as a range of values instead of a single finite value.) Much information was obtained regarding the proportion of heat loss through the boundary walls, from the many shelter experiments. This can be used as a base in establishing a procedure for estimating the percentage loss.

The adjustment made to the basic ventilation rate established from the adiabatic model is an attempt to correct a perhaps overly conservative result. The above is a simple illustration of the type of correction that can be made for boundary losses which is the most dominant factor that influences shelter heat removal other than the ventilating air itself. Cost of obtaining the boundary loss information must be carefully considered as it may offset the reduction in cost of the ventilating equipment. Unless a shelter is known to have an inordinately high percentage of boundary loss, the cost of correction would most likely not be justified. Therefore, it is probable in fact that for most shelters, the ventilation rates can be determined using the adiabatic method which involves no correction for heat loss.

(3) For a very limited number of shelters, it is possible for heat to flow into the shelter through the boundary walls due to solar effects. Since shelters are initially chosen for their radiation protection factor, most would be sufficiently protected from heat gain through the walls. Nevertheless for shelters in areas of very high dry-bulb temperatures, the increase in shelter load due to heat gain from the environment must not be neglected. It is therefore of importance to determine if ventilation requirements, obtained by assuming an adiabatic shelter, represents the maximum requirement, that is, does the adiabatic method produce the most conservative ventilation rate for a given set of conditions.

3. Computer Program for Transient Analysis

A parallel program in the study of shelter ventilation was the development of computer programs for transient analysis of shelter environment. General American Transportation Corporation, National Bureau of Standards, and the University of Syracuse participated in the development of separate programs. These reports are discussed in Appendix C.

The sophisticated method of determining shelter ventilation rates using a computer program considers the transient design weather cycle as well as the transient heat transfer of the boundary walls. It can be seen that a detailed input process is involved. Moreover, the reliability of the various input parameters must be established, thereby involving a risk of an overly precise calculation based on uncertain parameters. The weather information input for instance, is the result of a statistical data from which is generated the design day (see Part 3 of Appendix D). As stated there, in a pure analytical solution, for the dynamic input, the computer is fed the identical design weather cycle for the consecutive days for which the analysis is to be made to predict the shelter ventilation rate required. The actual weather occurrence of consecutive design days is an extreme condition; therefore, this factor would expect to provide a conservative result. It would be difficult, for instance, to develop a "design 14 day" cycle.

The mathematical part of the heat transmission problem, complicated as it is, is nevertheless well treated by the project personnel of NBS, GATX, and Syracuse University. Both analog and digital methods were

used in obtaining computer solutions to the mathematical problems. All of these methods were able to predict shelter conditions to a reasonably accurate degree, provided that the necessary input parameters were accurate. The heat transfer coefficients are relatively uncertain and difficult to obtain. In the theoretical work done by NBS (Ref. 13) it was related that coefficients obtained after a great deal of effort did not result in close agreement between theoretical and experimental results, and further trial and error adjustment had to be made.

The several computer programs developed yielded results that agreed closely with the experimental results, when the actual weather inputs were used together with much detailed information regarding the shelter properties.

The method of detailed analysis implies that each shelter can be analyzed individually, but it is questionable how readily such a program can be applied to the vast number of shelters involved.

The computer program has served nevertheless, to provide analysis for instantaneous shelter conditions. Thus the changes in shelter conditions during the initial period, the time to reach temperature stability, and the effect of boundary heat losses over a long period of confinement can be studied. As a result of its application in the experiments performed, a high degree of confidence has been established in its value, although for the present its use is limited. Since there are several programs that are operable and which are basically similar, it is recommended that a common computer program be established combining the merits of each of the several existing ones. Although the immediate application of such a program is not definite, it would serve as a basic tool for analysis of shelter conditions when further need for analysis arises.

4. Comparison of Experimental and Analytical Results

Reference has been made in various portions of this report to the ventilation tests performed at Providence, Rhode Island, by GATX. Through the experience and knowledge gained from numerous previous

shelter tests performed by several contractors, the experimental procedures and techniques of recent tests have been greatly improved and applied to the Providence test, resulting in more meaningful information.

A summary of the Providence test is presented, since much conclusive information was contained in it comparing the experimental results with predictions from the analytical program.

The test was conducted in an identified fallout shelter in the subbasement of the State Capitol building in Providence, Rhode Island. The shelter consisted of an L-shaped area and was marked for 500 occupants in an area of 4690 ft^2 (9.4 ft^2/occ). The duration of the test was 14 days (continuous), during which time ambient air was supplied at a near constant rate of 8.5 cfm/occ. Simocs were used to simulate the metabolic load. In addition to temperature and humidity measurements, heat meters were installed on all walls.

Data supplied to the computer program consisted of measured hourly temperatures, estimated cloud cover, day of the year, latitude of the shelter location, ventilation rate, shelter load, and shelter configuration and construction details.

A time history of the shelter conditions resulting from the following methods were compared:

(1) The predicted transient shelter conditions using input data supplied to the computer program.

(2) The predicted transient shelter environment assuming an adiabatic model.

(3) The time average of the adiabatic curve.

(4) The experimental results.

Figure F-1 is reproduced from the report of the Providence test and shows comparisons of the shelter DBT and ET variations over the 14-day period of the experimental and analytical results. These results show that the predicted and measured values, Item (1) and (4) above, are in very close agreement. The close agreement between the two curves would indicate that the heat transmission analysis was performed quite accurately.

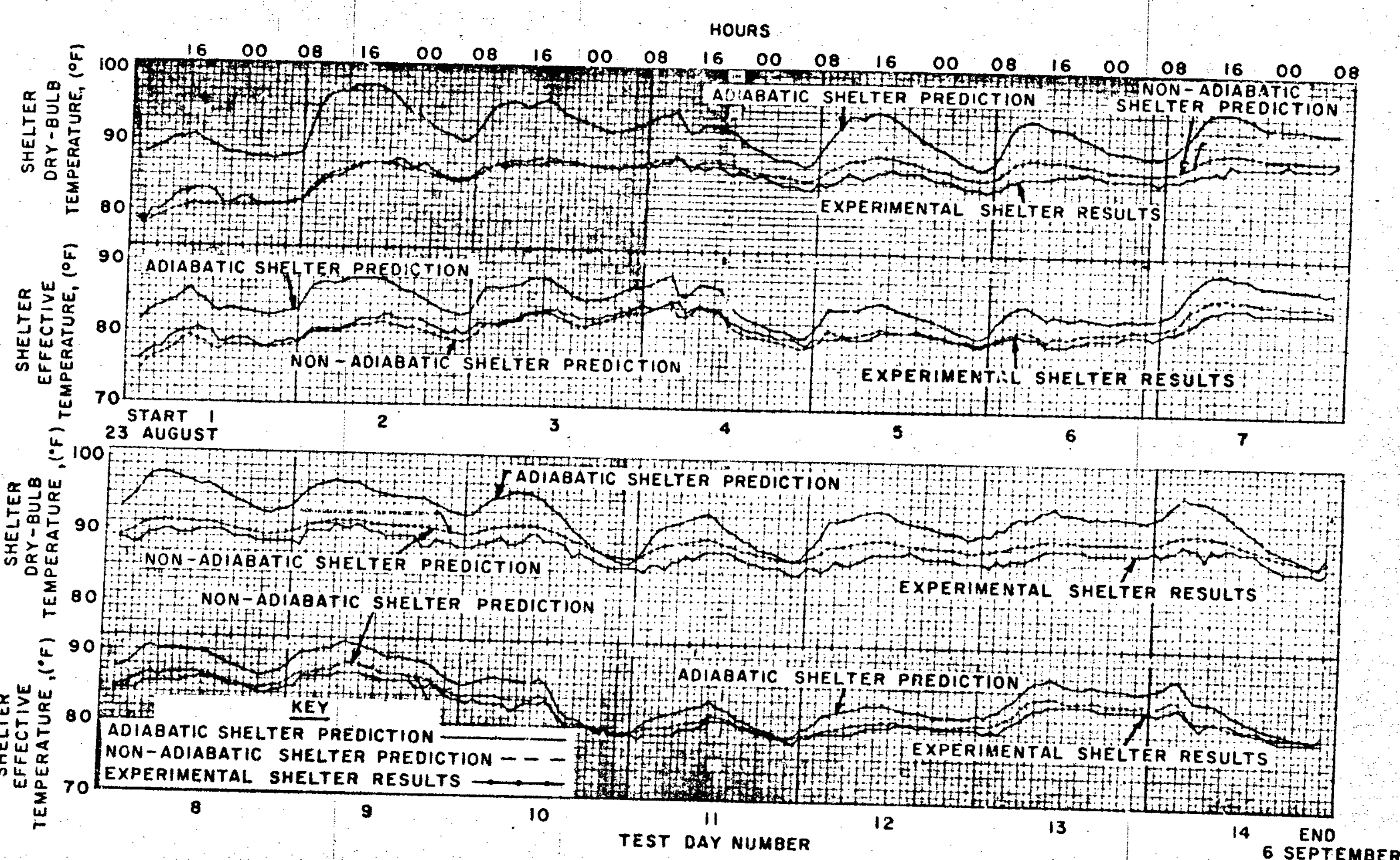

FIG. F-1 PREDICTED HOURLY VALUES OF SHELTER DRY-BULB AND EFFECTIVE TEMPERATURES

The deviation of the adiabatic shelter prediction curve [Item (2) above] from the experimental results is, principally, due to the transmission losses. An observation of the curve shows that the adiabatic curve approaches the experimental curve as the test progresses, indicating a decrease in heat loss rate because of the gradual rise in the adjacent area temperatures. The test was not necessarily run under design day conditions, but on a summer design day the heat loss would be decreased considerably and the adiabatic condition may therefore be closely approached.

In addition to the comparisons of the transient conditions, the steady-state results were compared. Twenty-four-hour average values were obtained of the transient shelter prediction results and of the experimental results. These were generally in agreement within 1.5^{o}F. On this basis it was suggested that the shelters be analyzed using daily average temperatures, thereby simplifying the problem. It is anticipated that additional analysis of data of other shelter experiments or the performance of further shelter tests will support this fact. (The merits of daily average data are also discussed in Part 2-b of Appendix B.)

It was seen from a comparison of the analytical and the experimental results that the computer program is in fact able to accurately predict psychrometric conditions of shelters of this type using test input data. Since the experiment was not carried on during a design summer day, the ventilation requirement determined was not the requirement for a design ambient condition. The value of the computer program lies however in the fact that a design day cycle may be used as an input to determine the critical ventilation requirement. (Part 3 of Appendix D suggests a method for obtaining the design day cycle.) It would have been interesting in the Providence analysis to have obtained a summer ventilation requirement independent of the ambient input and based on the Providence design day cycle, and to have compared the result with the requirements obtained by the adequacy factor method (Part 2 of Appendix D).

Since the computer program defines the transient condition in the shelter, it would allow an observation of the frequency and the number of hours that the shelter ET may exceed the shelter design criteria.

During the Providence experiment, considerable confidence in the computer program was developed, as was also an increased familiarity with the techniques of determining the extent of boundary heat loss. Little mention was made in the report of the effect of the other input parameters. Boundary heat loss follows ventilation rate as the second most important parameter in determining heat balance.

The Providence test is the only one of its type in which the test period was carried through for the full 14 days and using ambient air. The analytical method in the form of a computer program has been proven by comparisons with the tests of Providence and Bozeman.[15] It is recommended that discussions be held to determine the necessity of additional 14-day tests using ambient air to further verify the computer program and the application of the design day cycle.

Appendix G

METHOD OF PRESENTATION OF VENTILATION INFORMATION

The task of determining ventilation systems for individual shelters would most likely be undertaken by the local architectural and engineering organization under the supervision by the regional OCD offices or their representatives. Procedures for determining the local shelter ventilation requirements would have to be prepared in a form suitable for use by the shelter designers.

As a result of the extensive shelter ventilation study program, various methods of establishing ventilation rates for shelters have been presented, including the computer programs of GATX, NBS, and Syracuse University, the chart method of the University of Florida, the single point criterion system, and the adequacy factor curves. It has been concluded previously that the method of determining ventilation rates from the adequacy factor curves (based on an adiabatic shelter) is the most practical to date. Ventilation rates presented in the form of isoventilation contour lines on a geographical map of the U.S. (Fig. D-8) were obtained from the adequacy factor curves developed for 91 principal cities.

The distribution of the ventilation contour lines in Fig. D-8 are such that the definition of the ventilation rate is rather coarse, especially in the northern portion. The question arises whether the data for the sections comprising the cities and vicinity should be more finely broken down. Expansion of weather studies to additional centers would make possible the extension of isoventilation contour lines to state maps. In Appendix E it was recommended that studies be made on the validity of the weather bureau record as applied to the climate of the immediate vicinity of the shelters. Following such studies on several metropolitan areas, it is believed that decision could be made as to the extent to which the weather criteria areas should be broken down.

The freedom allowed the user to interpolate between the ventilation contour lines of Fig. D-8 may introduce inconsistencies from the correct ventilation rate, depending upon the user. Information is presented more positively by tabulating specific ventilation rates according to towns or counties, or by publishing more finely defined contour lines.

The ventilation rates as presented in tabular or chart form are based on an adiabatic wall model shelter. Instructions for applying correction factors to this basic rate where necessary must be presented with the data. In many cases it would not be economically feasible to obtain additional information for the specific shelters so that the correction can be applied to the adiabatic ventilation rate.

Data of the individual DB and WB, 1, 2.5 and 5 percent design day are available in the <u>ASHRAE Guide</u>.[1] For shelter designers who feel the need for a specific ventilation rate calculation, these data would be most useful, especially where adequacy factor data are not available, but studies must be made to determine if correction factors may be applied to the data in order to establish a single point psychrometric criteria (Appendix D, Part 1) that can be applied in a consistent manner.

Knowledge of the derivation and development of the adequacy factor and adiabatic method of determining ventilation rate, as well as familiarity with physiological tolerances, weather criteria, and boundary heat loss phenomena in shelters, will allow the shelter designer to use better judgment in selecting the specific shelter ventilation rates. Ventilation rates can be calculated relatively accurate for new shelters in which case the majority of the parameters would be known. Architects and engineers have had the opportunity to gain knowledge of the many facets concerned with the fallout shelter as a result of the Nuclear Defense Design courses offered by the OCD.

Appendix H

OTHER CONDITIONS AFFECTING SHELTER VENTILATION

The subject matter of the reports reviewed was primarily the determination of fallout shelter ventilation requirements to maintain a certain climate condition within the shelter. These ventilation requirements, as discussed in our report, are a function of certain pertinent parameters such as the weather data, shelter load, and physiological tolerance. Once a ventilation rate is established for the shelters, the design condition of the shelter will not be exceeded (for more than a predetermined percentage total time) if the required quantity of air is <u>supplied</u> and <u>distributed</u> throughout the shelter. This problem is one of specifying a ventilation system consisting of air movers and ducting compatible with a specific shelter. Offhand it would appear that a straightforward approach would be possible but it is now clear that further study of this particular problem is essential.

For example the PVK (packaged ventilation kit) was developed for purposes of ventilating with ambient air. In a recent study conducted by GATX it was found that the ventilation requirements cannot be met in a considerable number of below grade shelters if the standard PVK is used. This is due to the lack of sufficient openings for intake and exhaust air in many of the shelters and also due to the limited capacity of the PVK to overcome the pressure drops of the limited existing openings. In further studies directed toward the development of an optimum design for shelter ventilation equipment, the use of several ventilator types may be required including power driven versions so that the number of shelter facilities that can be ventilated would be increased. This work is presently in progress.

The amount of ventilating air supplied to the shelter is dependent among other things on the location of the PVK in the shelter, and the proper installation of the ducting system. In a recent shelter test at the University of West Virginia in which live occupants participated,

(including one of the authors) improper location and usage of the ventilating equipment had contributed to an intolerable condition in the shelter. Although the PVK's supplied to the shelter were rated to provide a sufficient ventilation rate for the number of shelterees, the air delivered was far below the requirement. The PVK location was poor; combined with this, the plastic ducting was awkwardly assembled, and many kinks and restrictions were introduced, thereby reducing substantially the performance that could reasonably have been expected with a properly arranged system.

Studies are also being made by GATX directed toward improved instructions to be supplied with the ventilators. It has also been suggested by GATX that from the shelter information gathered as a result of the national survey, it may be feasible to include in each instruction manual the recommended location of ventilators and ducting for each shelter, minimizing the chance of placement in a b d location. We would expect, however, that such pre-planning of the system configuration in all identified shelters would be a multi-million dollar project comparable in cost to the survey itself.

ACKNOWLEDGMENT

Figure D-2 and Table D-I of this report are reprinted from the paper by T. Kusuda and P. R. Achenbach, "Outdoor Air Psychrometric Criteria for Summer Ventilation of Protective Shelters," published in ASHRAE Transactions, Vol. 78, Part I, by permission of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

REFERENCES

1. ASHRAE Guide and Data Book--Fundamentals and Equipment for 1965 and 1966 (American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., New York, N. Y., 1965).

2. G. Engholm, "Physiological and Meteorological Aspects of Shelter Ventilation," report prepared for the NATO Civil Defense Committee, 29 June - 2 July 1965, General American Transportation Corporation, Niles, Illinois (1965).

3. D. H. K. Lee and A. Henschel, "Evaluation of Thermal Environment in Shelters," OCD Report TR-8 (August 1963).

4. E. C. Harvey and J. F. Maher, "Interim Solutions to Shelter Deficits," Phase I, Contract OCD-PS-64-75, Task 8, SRI Project 4764-081, Stanford Research Institute, Menlo Park, California (October 1965).

5. P. R. Achenbach et al., "Studies of Environmental Factors in a Family Size Underground Shelter," Mechanical Systems Section, Building Research Division, National Bureau of Standards, Washington, D. C. (March 1961).

6. H. F. Behls et al., "Operation and Maintenance Manual for OCD Shelter Test Equipment--Vol. 2: Valve-Type Simulated Occupant," Report MRD-1191-2, Contract OCD-OS-62-99, MRD Division, General American Transportation Corporation, Niles, Illinois (February 1964).

7. H. F. Behls and G. Engholm, "Operation and Maintenance Manual for OCD Shelter Test Equipment--Vol. 3: Test Vehicles," Report MRD-1191-2, Contract OCD-OS-62-99, MRD Division, General American Transportation Corporation, Niles, Illinois (December 1963).

8. F. M. Flanigan et al., "Final Report Summarizing Simulated Occupancy Shelter Tests Conducted During the Period July 5, 1962 through November 2, 1964," SRI Subcontract B-64225(4949A-17)--U.S. under Contract OCD-PS-64-201, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainesville, Florida (1965).

9. J. O. Gonzalez et al., "Second Simulated Occupancy Test, Summerlin Shelter, April 9, 1963 - April 20, 1963," Contract OCS-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainesville, Florida (1963).

10. F. M. Flanigan, "Simulated Occupancy Test, Boyles Shelter, Gainsville, Florida, July 30, 1962 - August 19, 1962," Contract OCD-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (1962).

11. J. O. Gonzales et al., "Simulated Occupancy Test, Napier Shelter, Gainsville, Florida, August 24, 1962 - September 10, 1962," Contract OCD-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (1962).

12. C. A. Madson et al., "Ventilation Test of a 210-Man Aboveground Shelter in Wilmington, North Carolina," Interim Report MRD-1195-55-1, Contract OCD-OS-62-134, MRD Division, General American Transportation Corporation, Niles, Illinois (February 1964).

13. T. Kusuda and P. R. Achenbach, "Numerical Analysis of the Thermal Environment of Occupied Underground Spaces with Finite Cover Using a Digital Computer," ASHRAE J., Vol. 6, No. 6, pp. 99-105 (June 1964).

14. C. A. Madson et al., "Ventilation Test of a 500-Man Basement Fallout Shelter in Providence, Rhode Island," Interim Report MRD 1268-30, SRI Subcontract B-64220(4949A-16)-US under Contract OCD-PS-64-201, MRD Division, General American Transportation Corporation, Niles, Illinois (March 1965).

15. C. A. Madson et al., "Summer Ventilation Test of an Aboveground Shelter in Bozeman, Montana," Interim Report MRD 1195-56-1, Contract OCD-OS-62-134, MRD Division, General American Transportation Corporation, Niles, Illinois (November 1964).

16. F. J. Drapeau and N. V. Baggette, "Mathematical Analysis of Temperature Rise in the Heat Conduction Region of an Underground Shelter," Mechanical Systems Section, National Bureau of Standards, Washington, D.C.

17. T. Kusuda and P. R. Achenbach, "Earth Temperature and Thermal Diffusivity at Selected Stations in the U.S.," Mechanical Systems Section, National Bureau of Standards, Washington, D.C. (February 1965).

18. T. Kusuda, "Least Square Technique for the Analysis of Periodic Temperatures of the Earth's Surface Region," Mechanical Systems Section, National Bureau of Standards, Washington, D.C. (September 1965).

19. T. Kusuda and P. R. Achenbach, "Digital Computer Simulation of Thermal Environment in Occupied Underground Protective Structures," Mechanical Systems Section, National Bureau of Standards, Washington D.C. (January 1965).

20. T. Kusuda and P. R. Achenbach, "Outdoor Air Psychrometric Criteria for Summer Ventilation of Protective Shelters," paper presented at ASHRAE Semiannual Meeting, Chicago, Illinois, 25-28 January 1965.

21. J. O. Gonzalez and F. M. Flanigan, "Simulated Occupancy Test of Bureau of Yards and Docks Protective Shelter, National Naval Medical Center, Bethesda, Maryland, February 28, 1964 - March 11, 1964," Contract OCD-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (1964).

22. J. O. Gonzalez, "Simulated Occupancy and Thermal Response Tests of Three Identical Protective Structures, Nevada Test Site, Mercury, Nevada, July 10, 1964 - August 12, 1964," Contract OCD-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (1964).

23. F. M. Flanigan, "Simulated Occupancy Test, Underground Concrete Structure, Lakeside, California, October 14, 1964 - November 5, 1964," Contract OCD-OS-62-116, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (1964).

24. E. E. Drucker et al., "A Generalized Computer Program to Analyze the Thermal Environment in Protective Shelters," Report ME 1109-6503F, Contract OCD-OS-63-221, Department of Mechanical and Aerospace Engineering, Syracuse University Research Institute, Syracuse, New York (March 1965).

25. R. J. Baschiere et al., "Analysis of Fallout Shelter Ventilation Requirements," Final Report MRD 1240, Contract OCD-OS-63-176, MRD Division, General American Transportation Corporation, Niles, Illinois (May 1964).

26. C. A. Madson and J. Leithem, "Experimental Studies of Fallout Shelter Ventilation Requirements," Report 1268-40, SRI Subcontract B-64220(4949A-16)-US under Contract OCD-PS-64-201, MRD Division, General American Transportation Corporation, Niles, Illinois (June 1965).

27. E. E. Drucker et al., "Thermal Environment in Community Shelters," Report ME 1034-6311F, Contract OCD-OS-63-20, Mechanical Engineering Department, Syracuse University Research Institute, Syracuse, New York (November 1963).

28. W. E. Strope, "Analysis of Shelter Ventilation Conditions," Draft Report, Office of Civil Defense, Washington, D.C.

29. J. Y. Wang, "Meteorological Aspects of Shelter Ventilation Design," study prepared for Stanford Research Institute (February 1966).

30. E. L. Hill et al., "Determination of Shelter Configuration for Ventilation," Draft Final Report R-OU-177, Contract OCD-PS-64-56, Research Triangle Institute, Durham, North Carolina (30 April 1965).

31. R. H. Heiskell, "Environmental Studies of a 100-Man Underground Shelter," TR-618; Contract OCD-OS-62-40 (Resch Subtask 1613A), U.S. Naval Radiological Defense Laboratory, 1 November 1959.

32. J. A. Hammes et al., "A Chronology of Two Weeks Fallout Shelter Confinement," Contract OCD-OS-62-226, University of Georgia, 1962-1963.

33. J. A. Hammes, "Shelter Occupancy Studies at the University of Georgia," Contract OCD-OS-62-226, 1962-1963.

34. R. W. Smith and C. A. Madson, "Psychological, Engineering, and Physiological Evaluation of Shelter Equipment and Procedures," Vol. III, General American Research Division, Contract OCD-PS-66-9, General American Transportation Corp. (February 1967).

BIBLIOGRAPHY

UNIVERSITY OF FLORIDA

Flanigan, F. M., and J. O. Gonzalez, "Moisture in Survival Shelters," Final Report, Contract OCD-OS-62-51 (April 1964).

Flanigan, F. M., et al., Final Report Summarizing Simulated Occupancy Shelter Tests Conducted During the Period of July 5, 1962 through November 2, 1964," SRI Subcontract B-64225(4949A-17)-US under Contract OCD-PS-64-201.

The following reports were prepared by the Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainesville, Florida, under Contract OCD-OS-62-116:

Flanigan, F. M., et al., "Simulated Occupancy Test, Summerlin Shelter, Gainesville, Florida, July 5, 1962 - July 18, 1962."

Flanigan, F. M., "Simulated Occupancy Test, Boyles Shelter, Gainesville, Florida, July 30, 1962 - August 19, 1962."

Gonzalez, J. O., et al., "Second Simulated Occupancy Test, Summerlin Shelter, Gainesville, Florida, April 9, 1963 - April 20, 1963."

Gonzales, J. O., and F. M. Flanigan, "Simulated Occupancy Test, Basement of Central Stores Building, Gainesville, Florida, September 14, 1962 - September 25, 1962."

Flanigan, F. M., "Simulated Occupancy Test, Reading Shelter, Reading, Pennsylvania, February 25, 1963 - March 18, 1963."

Dickert, J. W., et al., "Simulated Occupancy Test, Hersey Shelter, St. Louis, Missouri, June 5, 1963 - June 19, 1963."

Flanigan, F. M., and J. O. Gonzalez, "Simulated Occupancy Test, St. Louis Control Shelter, St. Louis, Missouri, June 7, 1963 - June 24, 1963."

Gonzalez, J. O., and J. W. Fairchild, "Simulated Occupancy Test, Francis Family Shelter, Tucson, Arizona, July 5, 1963 - July 15, 1963."

F. M. Flanigan, "Simulated Occupancy Test, Abo School, Artesia, New Mexico, July 10, 1963 - July 22, 1963."

Gonzalez, J. O., et al., "Simulated Occupancy Test, Airport Utility Shelter, Tucson, Arizona, July 19, 1963 - July 31, 1963."

Flanigan, F. M., "Occupancy Test, Roberts Dairy Company, Omaha, Nebraska, August 6, 1963 - August 20, 1963."

Gonzalez, J. O., and J. W. Fairchild, "Simulated Occupancy Test, Expedient Community Shelter, Fort Belvoir, Virginia, September 8, 1963 - September September 16, 1963."

Gonzalez, J. O., and J. W. Fairchild, "Simulated Occupancy Test, 200-Man Shelter, Protective Structures Development Center, Fort Belvoir, Virginia, September 22, 1963 - October 16, 1963."

Gonzalez, J. O., and J. W. Fairchild, "Simulated Occupancy Test, 1000-Man Shelter, Fort Belvoir, Virginia, October 14, 1963 - October 29, 1963."

Flanigan, F. M., "Simulated Occupancy Test, Family Shelter, Bozeman, Montana, February 1, 1964 - March 7, 1964."

Gonzalez, J. O., "Simulated Occupancy Test of Bureau of Yards and Docks Protective Shelter, National Naval Medical Center, Bethesda, Maryland, February 28, 1964 - March 11, 1964."

Flanigan, F. M., "Simulated Occupancy Test, North Arvada Junior High School, Arvada, Colorado, June 15, 1964 - July 6, 1964."

Gonzalez, J. O., "Simulated Occupancy and Thermal Response Test of Three Identical Protective Structures, Nevada Test Site, Mercury, Nevada, July 10, 1964 - August 12, 1964."

Flanigan, F. M., "Simulated Occupancy Test, Windowless Test Structure, Mercury, Nevada, August 18, 1964 - September 2, 1964."

Flanigan, F. M., "Simulated Occupancy Test, Underground Concrete Structure, Lakeside, California, October 14, 1964 - November 5, 1964."

GENERAL AMERICAN TRANSPORTATION CORPORATION (GATX)

The following reports were issued by General American Transportation Corporation, Niles, Illinois:

Libovicz, C. A., et al., "Ventillation Test on an Identified Basement Shelter in Houston, Texas," GATC Interim Report MRD 1195-52, Contract OCD-OS-62-134 (January 1963).

Behls, H. F., and G. Engholm, "Operation and Maintenance Manual for OCD Shelter Test Equipment, Vol. 3--Test Vehicles," GATC Report MRD 1191-2 Contract OCD-OS-62-99 (December 1963).

Behls, H. F., and G. Engholm, "Design, Specifications, and Cost Analysis for OCD Shelter Test Equipment," GATC Interim Report MRD 1233, Contract OCD-OS-63-99 (December 1963).

Behls, H. F., et al., "Manual of Procedures and Instrumentation for Shelter Occupancy Test," GATC Report MRD 1191-3, Contract OCD-02-62-99 (December 1963).

Behls, H. F., et al., "Operation and Maintenance Manual for OCD Shelter Test Equipment, Vol. 2--Valve-Type Simulated Occupant," GATC Report MRD 1191-2, Contract OCD-OS-62-99 (February 1964).

Madson, C. A., et al., "Ventilation Test of a 210-Man Aboveground Fallout Shelter in Wilmington, North Carolina," GATC Interim Report MRD 1195-55-1, Contract OCD-OS-62-134 (February 1964).

Behls, H. F., et al., "Ventilation Test of 300-Man Belowgrade Fallout Shelter in Wilmington, North Carolina," GATC Interim Report MRD 1195-55-2, Contract OCD-OS-62-134 (April 1964).

Libovicz, B. A., et al., "Summer Ventilation Test of a 200-Occupant Basement Shelter in Milwaukee, Wisconsin," GATC Interim Report MRD 1195-54-2, Contract OCD-OS-62-134 (April 1964).

Baschiere, R. J., et al. "Analysis of Fallout Shelter Ventilation Requirements, GATC Final Report MRD 1240, Contract OCD-OS-63-176 (May 1964).

Behls, H. F., et al., "Summer Ventilation Test of a Corridor-Type Fallout Shelter in Milwaukee, Wisconsin," GATC Interim Report MRD 1195-54-1, Contract OCD-OS-62-134 (September 1964).

Behls, H. F., et al., "Tandem-Drive Package Ventilation Unit," GATC Interim Report MRD 1244-4, Contract OCD-OS-64-22 (September 1964).

Nuccio, P., and G. Engholm, "Design and Development of a Plastic Packaged Ventilation System, Part I: Technical Proposal," GATC Proposal 90500 (September 1964).

Behls, H. F., et al., "Ventilation Aspects of a 300-Occupant Shelter Test in Athens, Georgia," GATC Interim Report MRD 1195-57, Contract OCD-OS-62-134 (November 1964).

Behls, H. F., et al., "Experimental Studies of Fallout Shelter Ventilation Requirements," GATC Final Report MRD 1195, Contract OCD-OS-62-134 (November 1964).

Baschiere, R. J. "Analysis of Aboveground Fallout Shelter Ventilation Requirements," GATC Final Report MRD 1240, Contract OCD-OS-63-176 (December 1964).

Madson, C. A., et al., "Summer Ventilation Test of an Aboveground Shelter in Bozeman, Montana," GATC Interim Report MRD 1195-56-1 (November 1964).

Bascheire, R. J., and G. Engholm, "Analysis of Fallout Shelter Ventilation Requirements," MRD Report 1266, SRI Subcontract B60421(4949A-16)-US under Contract OCD-OS-64201 (January 1965).

Madson, C. A., et al., "Natural Ventilation Test of an Aboveground Fallout Shelter in Baton Rouge, Louisiana," GATC Interim Report MRD 1268-20, SRI Subcontract B-64220(4949A-28)-US under Contract OCD-PS-64-201 (January 1965).

Madson, C. A., et al., "Ventilation Test of a 500-Man Basement Fallout Shelter in Providence, Rhode Island," GATC Interim Report 1268-30, SRI Subcontract B-64220-(4949A-16)-US under Contract OCD-PS-64-201 (March 1965).

Madson, C. A., and J. Leithem, "Experimental Studies of Fallout Shelter Ventilation Requirements," GATC Report MRD 1268-40, SRI Subcontract B-64220(4949A-16)-US under Contract OCD-PS-64-201 (June 1965).

Engholm, G., "A Novel Approach to Shelter Utilization," prepared for Scientific Working Party of the NATO Civil Defense Committee, 29 June - 2 July 1965 (1965).

Engholm, G., "Physiological and Meteorological Aspects of Shelter Ventilation," prepared for NATO Civil Defense Committee, 29 June - 2 July 1965 (1965).

Neveril, R. B., and H. F. Behls, "Package Ventilation Kit—Motor Test," GARD Interim Report 1268-4B, SRI Subcontract B-70925(4949-28A)-US under Contract OCD-PS-64-201 (August 1965).

Henninger, R. H., and C. A. Madson, "Natural Ventilation in a Basement Fallout Shelter in East Chicago, Indiana," GARD Report 1268-61, SRI Subcontract B-64220(4949A-16)-US under Contract OCD-PS-64-201 (January 1966).

Meier, H. A., and C. A. Madson, "Natural Ventilation in an Aboveground Fallout Shelter in Evanston, Illinois," GARD Report 1268-51, SRI Subcontract B-64220(4949A-16)-US under Contract OCD-PS-64-201 (January 1966).

GUY B. PANERO, INCORPORATED

The following reports were issued by Guy B. Panero, Inc., of New York, on SRI Subcontract B-64212(4949A-3)-US under Contract OCD-PS-64-201.

"Summer Ventilation Tests, Aboveground Fallout Shelter, Bronx County, N.Y.," Interim Report (January 1965).

"Summer Ventilation Tests, AMA Building, New York City," Interim Report (January 1965).

"Summer Ventilation Tests, Basement Fallout Shelter, Westchester County, N.Y.," Interim Report (February 1965).

"Winter Ventilation Tests, Underground Fallout Shelter, New Canaan, Connecticut," Interim Report (February 1965).

"Summer Ventilation Tests, Aboveground Fallout Shelter, 40 Wall Street Building, New York City," Interim Report (April 1965).

"Summer Ventilation Tests, P. S. No. 21 Fallout Shelter, Bronx County, N.Y.," Interim Report (May 1965).

"Ventilation Tests of Fallout Shelter Spaces in New York City and Vicinity," Final Report (February 1966).

MISCELLANEOUS

Achenbach, P. R., et al., "Studies of Environmental Factors in a Family-Size Underground Shelter," OCDM-NBS-60-1, Contract CDM-SR-59-33, Mechanical Systems Section, Building Research Division, National Bureau of Standards, Washington, D.C. (March 1961).

Lee, D.H.K., and A. Henschel, "Evaluation of Thermal Environment in Shelters," OCD Report TR-8, Office of Civil Defense, Washington D.C. (August 1963).

Drucker, E. E., et al., "Thermal Environment in Community Shelters (Review Draft)," Report ME 1034-6311F, Mechanical Engineering Department, Syracuse University Research Institute, Syracuse, New York (November 1963).

Hammes, J. A., et al., "Shelter Occupancy Studies at the University of Georgia, 1962 - 1963," Final Report, Appendices and Summary of Final Report, Contract OCD-OS-62-226, Civil Defense Psychological Laboratories, University of Georgia, Athens, Georgia (31 December 1963).

Samuel, J. A., "Environmental Engineering for Fallout Shelters," Office of Civil Defense, Department of the Army, Washington, D.C. (June 1964).

Kusuda, T., and P. R. Achenbach, "Numerical Analysis of the Thermal Environment of Occupied Underground Spaces with Finite Cover Using a Digital Computer," ASHRAE J., Vol. 6, No. 6, pp. 99 - 105 (June 1964).

ASHRAE Guide and Data Book--Fundamentals and Equipment for 1965 and 1966 (American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., New York, N.Y., 1965).

Kusuda, T., and P. R. Achenbach, "Outdoor Air Psychrometric Criteria for Summer Ventilation of Protective Shelters," paper presented at ASHRAE Semiannual Meeting, Chicago, Illinois, 25 - 28 January 1965.

Drucker, E. E., et al., "A Generalized Computer Program to Analyze the Thermal Environment in Protective Structures," Report ME 1109-6503F, Contract OCD-OS-63-221, Department of Mechanical and Aerospace Engineering, Syracuse University Research Institute, Syracuse, New York (March 1965).

"Military Specification, Package Ventilation Kit, 20-Inch Fan, Modular Drive (Civil Defense)" MIL-V-40645, Office of Civil Defense, Department of the Army (16 August 1965).

Harvey, E. C., and J. F. Maher, "Interim Solutions to Shelter Deficits," Phase I, Contract OCD-PS-64-75, SRI Project 4764-081, Stanford Research Institute, Menlo Park, California (October 1965).

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13. ABSTRACT

This report reviews and evaluates work performed by several contractors participating in the OCD fallout shelter ventilation program, including field ventilation tests using simulated occupants and the development of analytical models for prediction of ventilation requirements.

A series of meaningful experiments by the several contractors provided data in support of the analytical model. Emphasis is placed on weather criteria, which play an important part in determining required shelter ventilation rates. The adequacy factor (AF) method is found to be the most satisfactory criterion to date, by virtue of its basis upon simultaneous dry-bulb and wet-bulb temperatures available from the U.S. weather bureau. Curves of adequacy factor as a function of ventilation rate have been developed for 91 cities in the U.S., and shelter ventilation requirement maps showing isoventilation contour lines across the U.S. have been prepared from the AF curves. The data are based on an adiabatic model, i.e., the shelter load is assumed to be entirely removed by the ventilating air. The ventilation rate required is found to be greatly influenced by selection of the shelter effective temperature adequacy factor criterion (SET/AF criterion).

The required ventilation rate based on the adiabatic wall shelter model is found to produce realistic estimates under summer conditions for above-ground shelters. For below-ground or partially below-grade shelters, the ventilation rate required can be reduced if the surrounding soil is substantially below the ambient dry-bulb temperature. Further studies are required to develop a method of applying correction factors, such as for heat transfer, to the basic required ventilation rate of the adiabatic model shelter.

The simulated occupant (SIMOC) used in the tests is found to be a reliable approximation to the human metabolic load.

The relationship of weather data gathered by the Weather Bureau to microclimate shelter area data requires further study. Also found to require further study are methods of presenting required shelter ventilation rates, and the degree of detail within geographical areas.

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